Master Thesis

Master's degree in Industrial Engineering

Study and elaboration of an energy recommendation library for an online energy manager

Thesis

Author: Jordi Romani Vidal
Director: Oriol Gomis Bellmunt
Summon: June 2018

ETSEIB

Escola Tècnica Superior
d'Enginyeria Industrial de Barcelona

UPC

Abstract

Online energy audits are a disruptive and innovative approach that has many advantages compared to the traditional audits. However, assessing a particular consumer about what it needs to be done in order to be more efficient is a problematic that is difficult to generalize. Companies that deal with those new kind of energy audits struggle to solve this particular point.

In this work, a deep analysis of the online energy audit world is exposed. Moreover the problem of how to assess and advise a particular consumer by means of an online energy audit is tackled. To do that, this work focuses on the consumption habits of some profiles of the tertiary sector in order to obtain a list of general recommendations to increase efficiency.

The main goal is that each and every recommendation could be deduced only from the consumption analysis point of view. In other words, with no need for the energy manager to actually visit the building or install any additional hardware.

Contents

List of Figures

Preface

In the middle nineties, when most people did not know what Internet was, Jeff Bezos founded an online platform to buy books in where each client received personalized recommendations according to their previous purchases. Today this platform is known as Amazon and it had become the biggest Internet retailer in the world with more than $ 177.86 billion of annual revenue. Among many other things, one of the keys to his success resides in properly leveraging his client's data. When a user buys a particular item, when it visits or looks for a particular article it all gets registered in the client's profile. This information is used to elaborate personalized suggestions of other products that the user might be interested in.

In that manner, the traditional business of selling books lost an important market share against a competitor with worldwide presence, without any physical store and capable of selling more books than any book store in the world.

With the new advances in data mining, the online energy audits could become soon the new Amazon of the energy efficiency. The gain in scalability and data analysis capacity of this disruptive alternative lead to a better user experience and greater value for the final customer. The more weight this technology gains, the more will be the the people implied in energy efficiency and our society will become more sustainable.

Chapter 1

Introduction

In this chapter the contents and objectives of this work are exposed. The theoretical concept of virtual energy audit is explained, and the project structure including a brief explanation of each chapter is detailed.

1.1 Objectives of the project

The main objective of the work is to analyze a new and disruptive alternative for the traditional energy audits: the virtual energy audits. One of the main components of a virtual auditor engine is the library of energy recommendations. In this work, the elements that compound a virtual audit engine are analyzed and the working principle is explained. Moreover, a set of energy recommendations is elaborated and applied in a real case.

The presented work has the following specific objectives:

- Briefly introduce the future energy needs and show which is the main driver for the virtual energy audits.
- Analyze the traditional energy audit step by step in order to compare both approaches.
- Present the concept of virtual energy audit and analyze the current state of the art.
- Analyze the working principle of a virtual energy audit. Study all the systems that form the engine of the virtual auditor.
- Focus on the library of recommendations and elaborate an energy retrofit list with the data that the virtual energy auditor engine would need.
- Apply the elaborated library into a real case and study the recommendations proposed against the ones proposed by the traditional audit.

1.2 Scope of the project

The scope of the project is intended from an academical point of view. The elaboration and practical execution of the virtual auditor engine is an extremely complex task that would require deep knowledge in computer science and strong programming skills. For that reason, the practical execution is carried out by means of EnergyGrader utilities, which is an energy audit tool that will be exposed further on in this work.

The elaborated energy recommendation library is inserted into the EnergyGrader and it is tested against a traditional energy audit. The recommendation library includes the main sources of energy available in the tertiary sector. Energy recommendations that involve industrial processes are out of the scope in the recommendations library design since their are not scalable.

1.3 Project structure

This work is structured in seven chapters. In Chapter 2, as said before, a quick glimpse of the energy state of the world an its expected tendencies are analyzed. From that, the importance of the energy audits is tackled.

In Chapter 3, the traditional energy audits are analyzed. The exact definition of energy audit, the legal framework involved and the process of execution is detailed

In Chapter 4, the concept of virtual audit is exposed. The process of execution and the state of the art of this technology will be presented.

Chapter 5 goes a step further, and in there the working principle of a detailed virtual energy audit is explained. The concept of virtual auditor engine is explained along with the different parts that compound it. In Chapter 6 an energy recommendation library for an online energy manager is built up.

Finally, in Chapter 7 the elaborated energy audit is inserted into a virtual energy audit tool and executed in a real case application.

Chapter 2

The need of energy audits

In this Chapter, a glimpse of the worldwide energy situation and its future prospects are presented. From that, the importance of the energy efficiency and how it is related with the energy audits will be explained.

2.1 Current situation

The International Energy Agency (IEA) has a database that contains information and indicators about the social, economic and energy state of the world. The last year with available information was 2015. During that year [2]:

- The world population was 7333.78 millions people.
- The total energy production was 13790.02 Mtoe.
- The total electric consumption (production + imports - exports - losses) was 22385.81 TWh.
- The amount of CO_2 emitted during that year was 32294.21 Mt of CO_2.

Figure 2.1 shows the total primary energy supply in 2015 [2]. It can bee seen that 81.5 % of the primary energy worldwide produces CO_2 emissions.

The final use of this primary energy is sketched in Figure 2.2. It can be seen that only a 18.5 % of the primary energy was used to produce electricity in 2015. The rest was employed in oil products, natural gas and fuels.

From the above information it may arise the concern of the environmental impact that humankind has on earth.

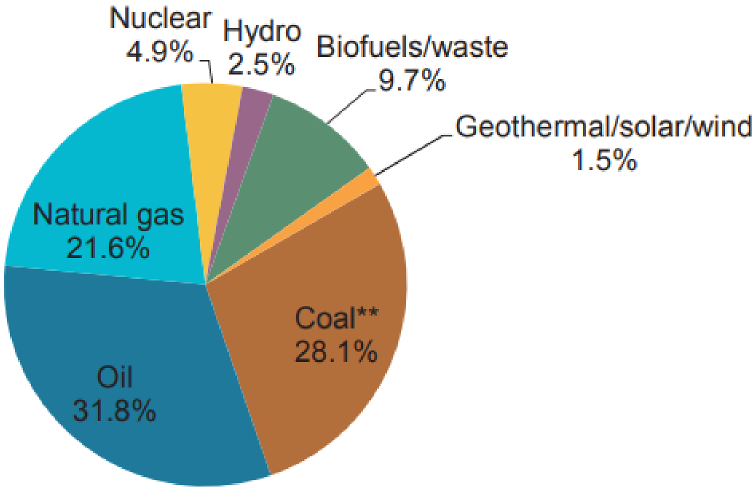


Figure 2.1: Worldwide share of primary energy supply in 2015 [1]

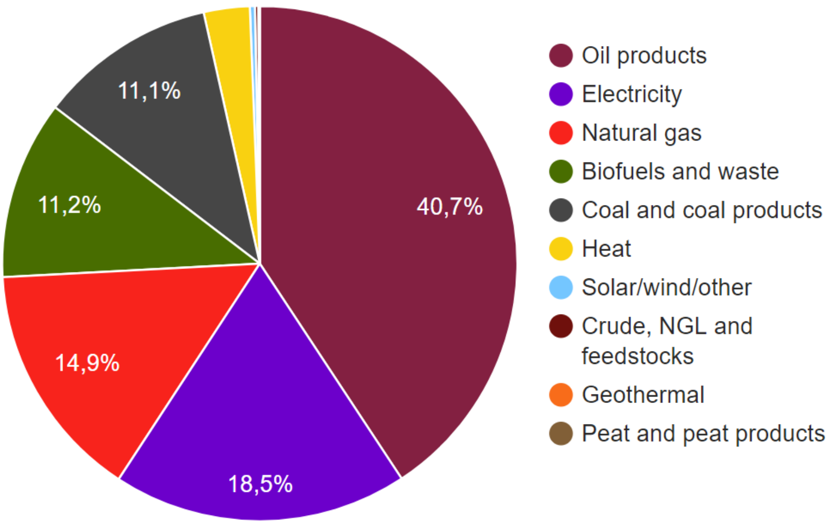


Figure 2.2: Worldwide consumption of primary energy in 2015 [2]

2.2 Future energy demand

As it can be seen in Figure 2.3, the energy consumption has been increasing in the last few years.

According to the World Energy Outlook [4], the world population is estimated to annually grow 1%, meaning that by 2030 it will be approximately over 8200 million people. This is directly translated into an increment of the global energy consumption as the U.S. Energy Information Administration points out in its International Energy Outlook of 2017 [4]. This increment in the forecasted consumption is plotted in Figure 2.4.

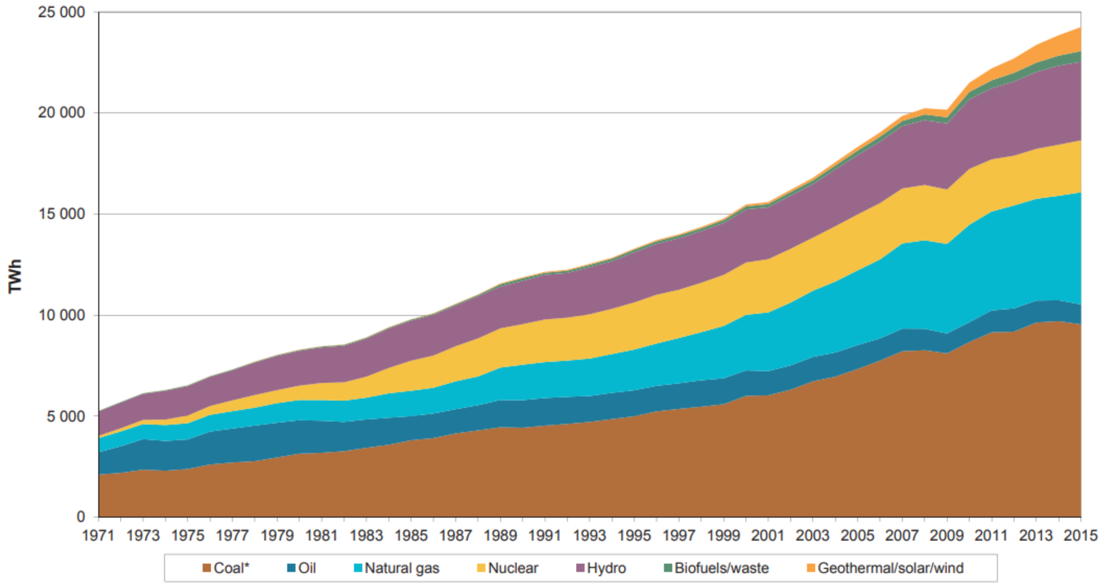


Figure 2.3: Evolution of the worldwide sources of electricity generation [3]

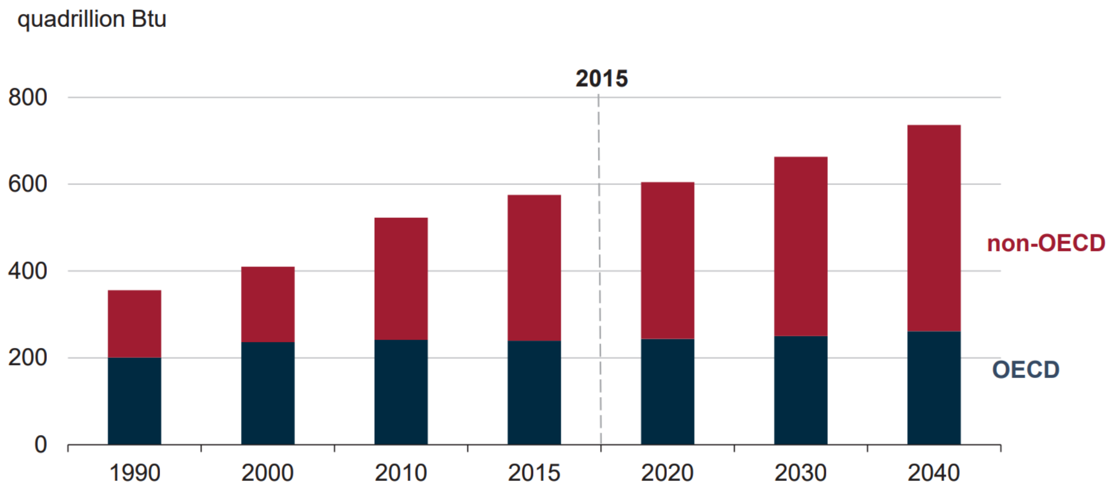


Figure 2.4: Forecasted energy consumption according to IEO 2017 [4]

This increase in consumption is caused by the development of the Asiatic countries, i.e China and India, as Figure 2.5 denotes.

Considering how the energy is being produced nowadays (see Figure 2.1), and the actual tendency (see Figure 2.3) the environmental impact that humankind will have is forecasted to be worse than in 2015 if no further actions are taken.

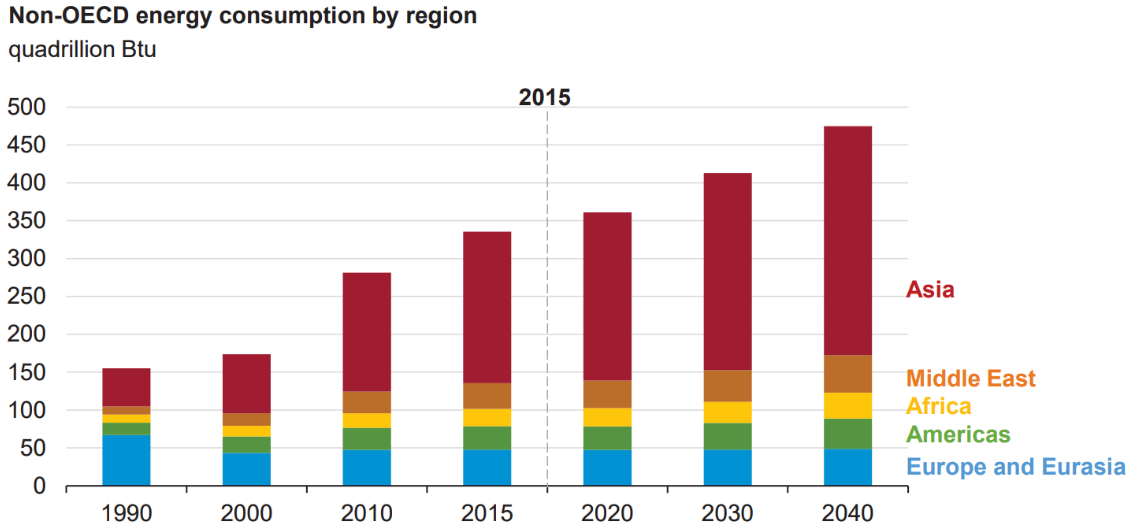


Figure 2.5: Forecasted energy consumption by region [4]

2.3 Importance of the energy audits

Seeing the scenario presented above and given the perspectives on population growth and energy consumption, the only possible solutions are either to produce more green energy or to consume more efficiently.

Green production is achievable with the growth of renewable energies. In Figure 2.3 it already can be seen in the last years of the graph that renewable production is thinly increasing. Moreover, the expected advances in fusion energy may be the solution to the human electric energy needs in the long term [12].

In the meanwhile, the short term solution is to better use the actual energy produced in order to reduce consumption. There exist a lot of tools designed to achieve that purpose such as the energy audits, the implementation of energy recommendations, the measuring and verification plans, or standards like the ISO 50001. The world of the energy efficiency is huge and broad, but before starting to improve a system it is extremely important to precisely know it, and this is the main purpose of an energy audit. This is the main purpose of the energy audits.

Chapter 3

Traditional energy audits

This Chapter describes the traditional concept of energy audit, the legal framework and the process required to realize it.

3.1 Definition

In November 14^{th} of 2012 the European Directive 2012/27/EU had been approved. That directive defines an energy audit as an independent documented and systematic process aimed to gather and objectively evaluate data about an organization with the aim of [13]

- Acquire a reliable source of knowledge about the energy consumption and its associated costs for a particular building or groups of buildings.
- Identify and characterize the factors that affect the energy consumption.
- Detect opportunities for energy savings and diversification, evaluate its benefits from an energy point of view, asses the environmental impact of the proposed recommendation and its economic analysis in terms of cost and maintenance.

3.2 Legal framework

The Energy Efficiency Directive 2012/27/EU establishes a common framework for the promotion of energy efficiency among the EU members. The directive introduces legally binding measures to encourage a rational use of energy at all levels of the supply chain [13]

The directive is implemented by the EU members by means of its own legal framework. In Spain the norm UNE 216501 defines the methodology to realize an energy audit according to the Spanish legal framework. It is a quite open standard that the energy auditor needs to know along with other complementary standards such as [14]

- Norm UNE-EN ISO 50.001 for energy management systems. Approved on June 2011.
- Reial decret 1027/2007 whereby it gets approved the RITE, the standard for thermal systems in buildings.
- Reial decret 314/2006 whereby it gets approved the CTE, the technical norm for buildings.
- Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control.
- Directive 2006/32 / EC of the European Parliament and of the Council of 5 April 2006 on the efficiency of the final use of energy and energy services and repealing Council Directive 93/76 / EEC.

3.3 Classification of the energy audits

Energy audit	**Definition**
Global	It deals with the whole building or facility. The purpose of a global energy audit is to analyze the different sources of energy and their usage.
Partial	It refers to the energy audits that focus only on a part of the building, a particular energy source or that deal with a specific part of the manufacturing chain. The partial energy audits are usually executed after a global energy audit in order to analyze in more detail aspects that can not be considered in a global energy audit.
Maintenance	The purpose of the maintenance energy audits is to focus on the maintenance tasks from an energy point of view. The idea is to elaborate an energy balance of the predictive, preventive and corrective maintenance tasks in order to make them become more efficient.
Monitoring	Once the energy audit has been performed, a set of energy recommendations had been proposed. Those recommendations give an approximate estimation of their potential energy savings. Once applied, the monitoring energy audit checks if the predicted energy savings adjust to reality and corrects potential deviations by means of new proposals and tools.
From new project	These types of energy audits aim to analyze a project from an energy point of view before its realization. These type of energy audits ensure that the building or facility will be build up with the best solutions in energy efficiency.
Energy management	The purpose of these type of energy audits is to improve the energy management system of the facility. This kind of energy audits could be aimed to implement the norm EN-16.001/ISO-50.001.

3.4 Process of execution

This section deals with the process of execution of a traditional energy audit. Planing the process is very important since it will determine the energy systems that will be analyzed during the on-site visit of the facility hastening the process and making it more efficient. The process is described as follows and it can be extrapolated to any kind of facility, process or sector [14].

3.4.1 Data request

The data to be requested helps the auditor to get in touch with the energy process of the facility or building. It basically consists in the inventory of the equipment that consumes energy, its technical data-sheets, all the available electricity and natural gas invoices, operating hours, curve loads if available and all the information that could help understand the overall process. If the facility has any particular singularities the energy auditor should get to know it in that phase. The information should be provided by the building or facility manager.

3.4.2 Technical documentation review

Usually the the technical information provided by the facility manager is not enough. Most of the times the energy auditor only gets to know the model of a specific equipment and it is necessary that he or she looks for the technical datasheet himself or herself. Other technical documentation that could be necessary in some cases is:

- Flow diagram of the process
- Operational plan
- Single line diagram of the electric system

3.4.3 On-site visit

In this phase the auditor can first-hand see the equipment and the energy systems. On-site measurements can be done and the actual state of the equipment can be assessed. In this phase the information of the previous phases can be validated and doubts from the energy auditor can be resolved.

3.4.4 Analysis of the current energy situation

In this phase the current energy state of the building or facility is analyzed. To do so, an energy disaggregation study is carried out. With the energy disaggregation it can be explained how the energy is consumed and for which equipment. If different energy sources are analyzed in the energy audit it gets also reflected in the disaggregation. For instance, with that analysis it can be known how much energy is consumed for the cooling system, how much by the lightening system, etc.

This analysis is elaborated by means of direct measurement, from the information gathered in the electric and natural gas invoices, by analyzing the rated power of all the equipment and considering their hours of use, etc. The typical points in which the analysis of the energy auditor focuses are:

- Analysis of the historical energy consumption of the last 24 months.
- Efficiency analysis of the main equipment and the distribution system.
- Energy demand curves of the building.
- Analysis of the CO_2 emissions of the building.
- Energy forecast.
- Energy ratios by surface, HDD, CDD, etc.

The comparison of this analysis with reference values known from the experience of the energy auditor helps to asses how much efficient the building is and it allows to estimate the potential energy savings. This analysis helps to identify which are the potential energy measures suitable for that particular building.

3.4.5 Economic analysis

The economic analysis is performed once the energy situation is known in detail and aims to determine the economical costs associated to empower each part of the building's systems. In this phase it is also determined whether the electrical supply contract is the most efficient one.

3.4.6 Energy baseline

The baseline is the energy reference state from which the effects of the energy recommendations to be applied will be evaluated. The baseline or reference state has to consider production variations, changes in the scheduled activity of the building, increases in staff and other exogenous factors that may affect the energy consumption. In that manner it can be better ensured that any deviation between consumption and the baseline will probably be due to the effect of the energy measures applied.

The facility managers or energy managers and the energy auditor need to agree on the baseline and reach a consensus since it will be the key factor to evaluate the performance of the energy recommendations.

3.4.7 Identify the potential energy saving recommendations

At this stage, the energy auditor has a deep knowledge of the energy situation of the building and is capable of defining specific and tailored energy recommendations to tackle the main inefficiencies. The energy auditor has experience on the field, is updated with the newest technologies and is aware of the particularities of the building. In a general basis, the energy recommendations basically target:

- In the manufacturing process of the facility (if there is one).
- In the main systems of the building (cooling, heating, lightening, etc).
- In auxiliary or secondary systems.
- In the source of energy used: gas, electricity, biomass, etc. For example, replacing a natural gas boiler for a biomass one.
- Behavioral recommendations: implement good energy habits among the employees or staff.

3.4.8 Economic and energy analysis of the energy recommendations

Once the potential energy measures are identified, its technical and economical feasibility are evaluated.

The energy analysis consists in study the energy consumption once the recommendation is implemented by means of an energy simulations. The detail of this simulations depends on the type of energy audit and the required accuracy.

Concerning the economic analysis, it considers the energy recommendation as an investment and therefore economic metrics such as CAPEX, OPEX, ROI, NPV or the lifetime of the recommendation are calculated.

Additionally, the environmental effects of the recommendation are also considered in the analysis with indicators like the equivalent kg of CO_2 not emitted due to the recommendation.

3.4.9 Final energy audit report

The final report contains all the previous points and reflects the information gathered during the energy audit, the energy and economic analysis and a list with the energy recommendations identified by the energy auditor. The person who reads this report should be able to know precisely:

- The current energy consumption of the building or facility.
- The energy costs of the building or facility.

- The current energy situation of the building: energy efficiency and performance of the current systems.
- The main available options in order to improve energy efficiency.
- Potential energy savings.
- Investment costs required to obtain those potential energy savings.

Chapter 4

Virtual energy audits

This Chapter deals with the virtual energy audit concept, its process of execution and the current state of the art of this disruptive approach.

4.1 Definition

A virtual energy audit pursues the same goals as a traditional energy audit but the process of execution is much simpler, completely automated and scalable. The idea is to give insights about the energy state of the building without carrying out any on-the-spot measurements or visits from the energy auditor side. This significantly reduces the time of execution and the costs. As in a traditional energy audit, energy retrofits are given once the virtual audit is executed pointing to solve the main inefficiencies detected.

4.2 Process of execution

4.2.1 Data request

This is the most important point in a virtual energy audit since it is the only available source of information of the building and it will determine the accuracy of the audit itself. The data to be requested can be divided in two main blocks.

Consumption

The consumption data is the one that will help the virtual auditor to get a picture of the energy state of the building. The frequency of the consumed data will mainly depend on whether the facility is already monitored or not. Usually, for non monitored facilities the available data in terms of energy consumption are the electrical invoices, which are usually on a monthly basis. Monthly frequency of data could work for a virtual energy audit but is not enough to determine the hours of activity or the standby consumptions. If the data available is in an hourly frequency or below the load curve obtained is precise enough to differentiate the active hours from the non active ones and determine the standby consumption of the facility. Other sources of energy such as natural gas are significant for the virtual energy auditor.

Metadata

The metadata refers to the full set of data that gives extra context and is useful to better analyze the consumption data and do a more precise energy audit. Obtaining the proper metadata is a trade-off between gaining accuracy and losing scalability. The more metadata required the more friction will have the process of obtaining that data and more difficult will be to extrapolate the process of virtually auditing a huge portfolio of buildings. Therefore, the metadata obtained should add significant value to the analysis. The main aspects to consider as metadata are summarized below and sorted from huge value to less value.

- Location: The precise location of the building allows to know its local weather conditions by means of a GIS meteorological database. The weather conditions have a huge impact on the energy usage especially in the heating and cooling systems.
- Activity: The activity of the building is directly linked to its hours of use and the energy profile, two key factors in the energy analysis.
- Surface: The area is important in the benchmarking since it allows to normalize the energy consumption and compare buildings with different size but similar energy profile.
- Construction year: The construction year aids to evaluate the performance of the building's envelope in terms of thermal insulation. Another data that could be useful is the year of installation of the main systems of the building in order to assess its efficiency and compare it with the current technology.
- Contracted power and tariffs: If possible, the virtual energy auditor could compare the building's tariff with the current ones present in the market and try to cut energy costs by recommending a better tariff.

4.2.2 Data processing

Once the data has been collected the engine of the virtual auditor performs an energy and economical analysis by comparing the building's performance to similar facilities. Once the building is analyzed, personalized energy retrofits are proposed from a library of energy recommendations. Next chapter goes through the theoretical concept of engine for virtual energy auditors and explains how multiple buildings are benchmarked and the technical tools behind that process. It also explains the concept of energy recommendations library, which is the main part of this work, and how the recommendations are selected and tailored.

This step of the virtual energy audit englobes multiple parts of the traditional energy audit, more specifically the on-site visit, the analysis of the current energy situation, the economic analysis, the identification of the potential energy saving recommendations and its energy and economic analysis.

4.2.3 Final report

Finally, once all the data has been processed and the energy recommendations had been selected the last part is to elaborate the final energy report. Some of the current platforms that perform virtual energy audits display this information in a graphical interface that can be viewed with a computer.

4.3 Advantages and disadvantages of the virtual energy audits

4.3.1 Advantages

The advantages of a virtual energy audit can be summarized as:

- Low cost: The human resources involved in a virtual energy audit are significantly lower than in a traditional energy audit. The costs associated to a virtual audit are due to software and the managers in charge to fill the forms. The costs in software could be up to 240 €and the time required to fill the forms is less than 2 hours. On the other side, the cost for a traditional energy audit is strictly related to the size of the building and the level of detail and accuracy and the prices could vary from 1000 € to 50000 [15]. In any case, the difference in price is huge and the dimensions of the building do not have any effect in software costs.
- Low time: Since virtual energy audits do not require an on-site visit of the building the time of the overall process is reduced considerably. In fact, a virtual energy audit could be executed in 5 h [16], which is at least 98 % faster than a traditional energy audit which takes between 15 days and 1 full year [17] depending on the size of the building and accuracy.
- Scalability: Another of the main advantages of virtual energy audits is that the process could be replied to a lot of buildings with a low impact in time and costs. This is especially useful when the client has a huge portfolio of buildings to analyze and a limited budget. In that manner, the energy manager could have a full picture of his or her portfolio of buildings and focus resources in the ones that need more attention.

4.3.2 Disadvantages

The disadvantages of a virtual energy audit can be summarized as:

- Accuracy: This is the main drawback of the virtual energy audits. The error in these kind of energy audits is around an 8 % compared to traditional energy audits [16]. Moreover, the accuracy depends also in the activity of the building. The initial prototype of the RemBAP tool of DEXMA Sensors S.L for virtual energy audits achieves less error for the energy disaggregation in offices and retail rather than in other sectors since the variability is lower.

- Lack of data: Another factor that affects accuracy is the resolution of the available data or the lack of data itself. This point affects also the traditional approach in energy audits, however, since the only point of contact with the building is the data, a missing invoice or period of data will have several effects on the audit accuracy.

4.4 State of the art

Most of the tools available for virtual energy auditing are currently applied to drive customer engagement in utilities. In a certain manner, the utilities add an extra service that gives value to their clients even though the scope of the audit is to consume less. Although it seems paradoxical, customer retention provides more revenue despite reducing consumption.

Pointing in that direction, most of the available virtual audit tools are applied in the residential sector, however, there are cases in where the application is company oriented. In that second group the analysis is usually more accurate and so are the obtained results in terms of energy savings. FirstFuel and DEXMA belong to that second group since they target does not include the residential sector.

Some example of companies that develop a virtual energy audit tool are:

4.4.1 FirstFuel

FirstFuel is an American company expert in energy management and virtual energy audits. They did a prove of concept in a joined project with the American utility PG&E (Pacific Gas and Electric Company) in where FirstFuel's tool Rapid Building Assessment was proved against 7 on-site energy audits carried out by an independent third party, Enovity Inc.

FirstFuel conducted remote energy audits of those 7 buildings which had various sizes (from 1200 m^2 to 45000 m^2) and use types (Municipal, Animal Hospital, Library, Museum, etc). The results where compared to the traditional energy audits and the conclusions are as follows [5].

- The energy disaggregation error was 8% in average and for some specific cases such as cooling, heating and plug loads the error was between 1% and 7%.

- Average difference of estimated savings between on-site and virtual audit was 7%. Four of seven sites produced savings differences of less than 5%

- The FirstFuel process was three times faster than the traditional approach.

This particular case of virtual energy audit is slower than other approaches since FirstFuel manually validates and calibrates the results of their engine with a team of engineers with experience in the sector. The pipeline of their overall process is depicted in Figure 4.1. This particular approach is specific from FirstFuel.

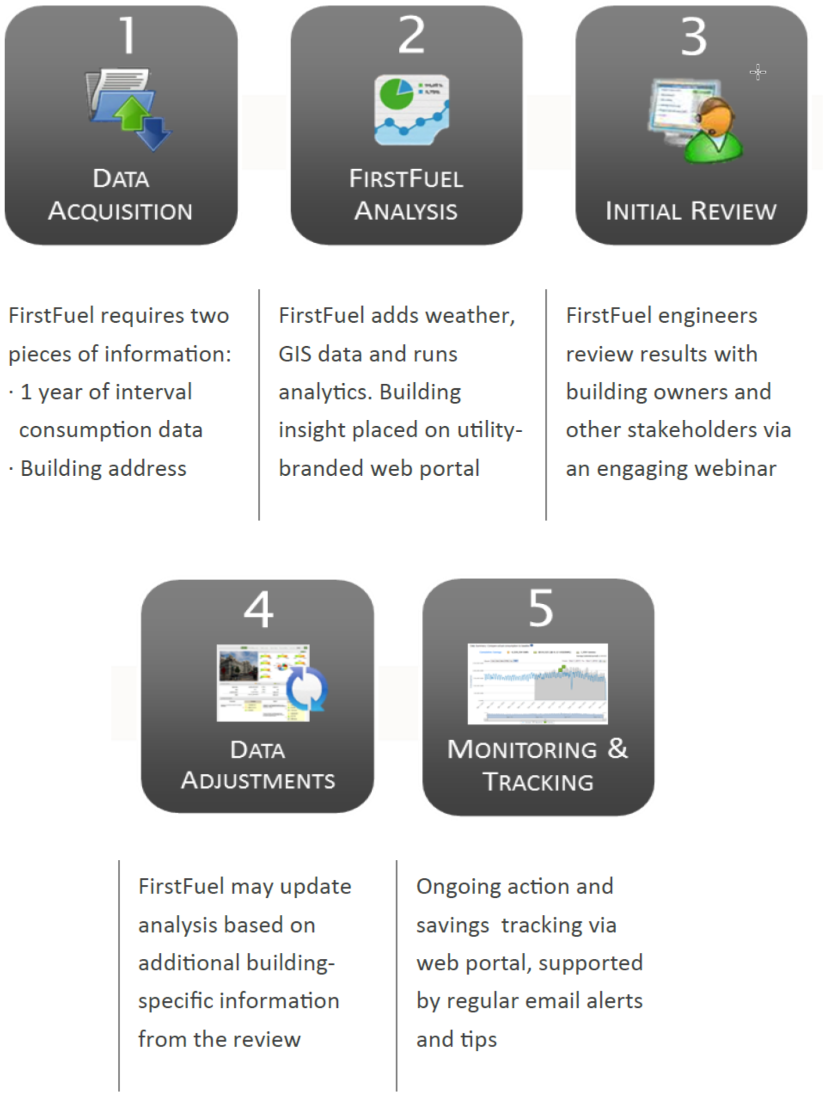


Figure 4.1: Pipeline of Rapid Building Assessment tool [5]

4.4.2 Bidgely

Bidgely is an American company focused on virtual energy disaggregation on the residential sector. Bidgely offers its software and data capacity analysis to electrical utilities in order to prompt customer engagement. Their platform is via mobile app and offers direct communication with the user. The consumption data is directly obtained from the utility side.

Their platform uses NILM (Non-Intrusive Load Monitoring). This technology consists in keeping track of the electric fingerprint of the main home appliances [6]. This is used to differentiate for instance a refrigerator from an oven as Figure 4.2 denotes. Moreover, this analysis is aid by the metadata from that particular user which in the case of Bidgely it is requested through the mobile app. The metadata consists in a survey in where the client specifies the appliances that his or her home contains and the energy source from the heating system, the grill, the oven, the water heating, etc [18]. From electric fingerprint the hours of use of each appliance are known from direct measurement and it is possible to accurately tell how much does each appliance consume and completely determine a whole picture of the energy state of the house.

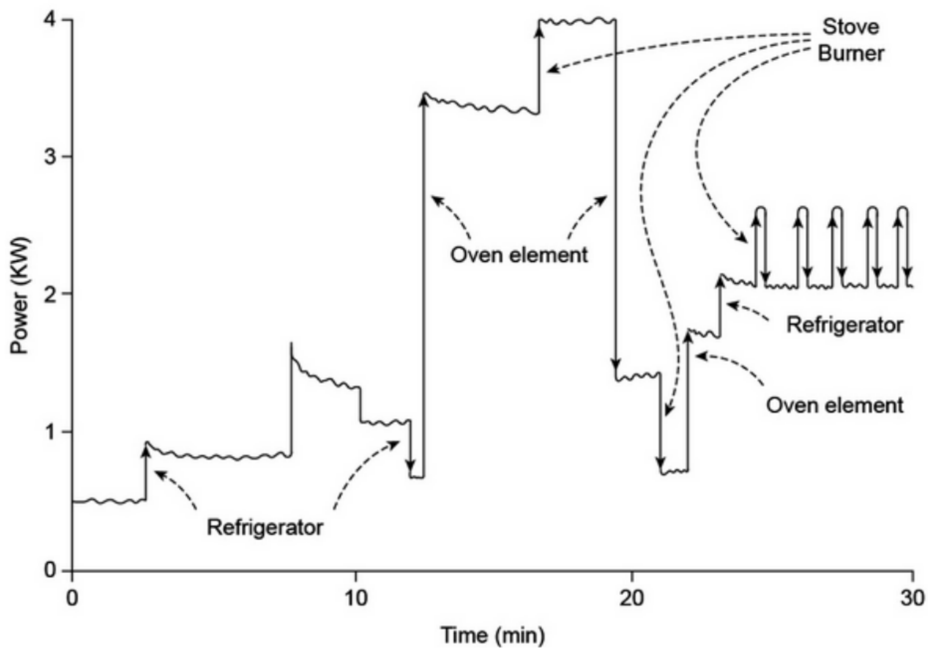


Figure 4.2: Non-Intrusive Load Monitoring in home appliances [6]

The drawback of this approach is that it requires data at high frequency which is totally incompatible for a final consumer without a smart meter and consumption readings on a monthly basis. When this occurs, the disaggregation is performed by means of benchmarking, i.e comparing the user with other similar users whom his/her energy disaggregation is known. Next chapter gives more insights about this benchmarking technique.

4.4.3 The Energy CheckUp project

The Energy CheckUp is an European project that provides a free online analytic tool for energy analysis, benchmarking and energy saving measures focused in SMEs. The platform asks several questions about the facility such as [7].

- Sector, allowing to choose between hotel and catering industry, retail food, retail non-food and office.
- Annual consumption of electricity. Other energy sources such us natural gas, propane, oil, wood or the total heat consumption in MJ can be added.
- Constructive details about the building such area, year of construction and location, envelope insulation.
- Lightening system, % of area covered by light and technology used, hours of use.
- Cooling system, temperature set-point.
- Heating system, technology and energy source, temperature set-point.

At the end of the survey the engine disaggregates the use of energy as Figure 4.3 shows and gives a set of energy recommendations shown in Figure 4.4.

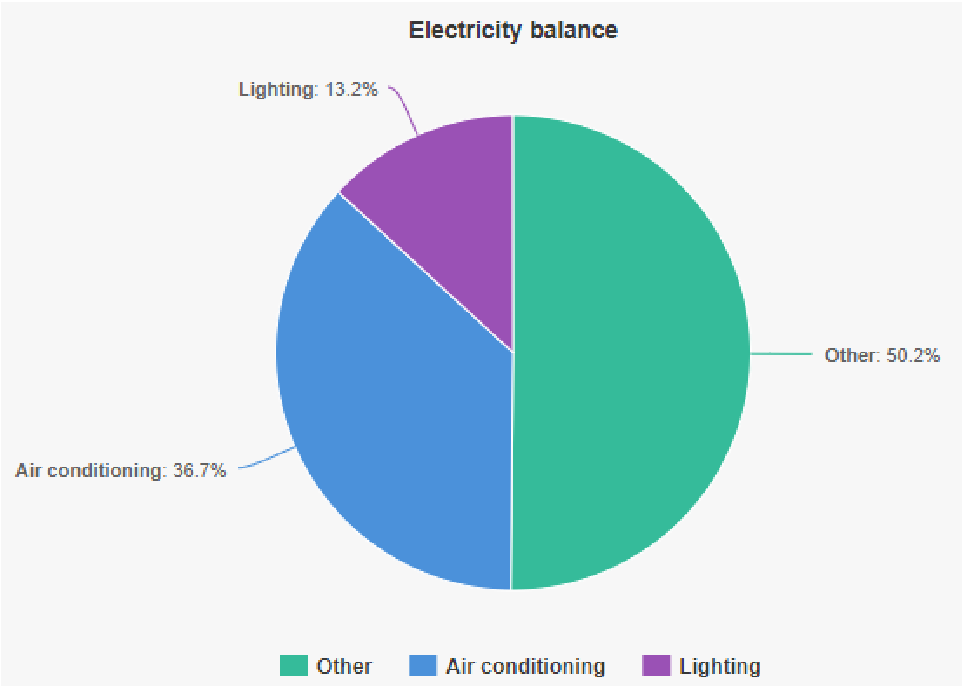


Figure 4.3: Load disaggregation from the CheckUp project [7]

By clicking on a specific recommendation a brief description of the recommendation pops up and in some cases a short video detailing it.

4.4.4 EnergySavvy

EnergySavvy is an American company that sells software and services to companies with the aim to prompt customer engagement. Their tool is called ROA (Residential Online Assessment) and enables homeowners to complete an online energy audit to understand

1. INPUT 2. BENCHMARK 3. SCREENING 4. RESULTS **5. MEASURES**

Measures

Category	Measure	Payback within
Building and insulation	Floor insulation	4-8 years
Building and insulation	Insulated and/or reflective glazing	6 - 10 years
Building and insulation	Controllable solar shading systems	1 - 5 years
Building and insulation	Lower losses due draught	< 1 year
Building and insulation	Create airlock at entrance	2 - 5 years
Building and insulation	Good housekeeping building and insulation	< 1 year
Hot tapwater	Apply water saving components on showers and taps	< 1 year
Hot tapwater	CO2 heatpump for hot tapwater	3 - 7 years
Lighting	Apply presence-dependent lighting	1 - 3 years
Lighting	Replace traditional lighting by LED	0,5 - 2 years
Lighting	Replace fluorescent lighting by high frequency fluorescent lighting	3-5 years
Lighting	Apply daylight dependent regulation on dimmable lighting	2-8 years

Figure 4.4: Energy recommendations from the CheckUp project [7]

their home's energy profile. The municipal utility of San Antonio CPS Energy acquired EnergySavvy's services and by means of ROA nearly tripled the number of completed retrofits reducing the cost to acquire a retrofit by more than 6 times compared with an in-home audit [19].

This tool consists in a survey in where the customer answers questions relative to his or her house such as:

- Home type, number of floors.
- Year of construction and other constructive details such as insulation of the walls, roof, windows, etc.
- Total surface.
- Location by means of ZIP code in order to connect with a GIS meteorological database.
- How drafty the house is and how much shading it has.
- Cooling system, technology used and temperature set-point.
- Heating system, technology and energy source, temperature set-point.

- Main appliances, source of energy used, antiquity and style.
- Usage of the lightening system and type of bulbs employed.

The survey is assisted by a set of images that help the user answer the questions as Figure 4.5 shows.

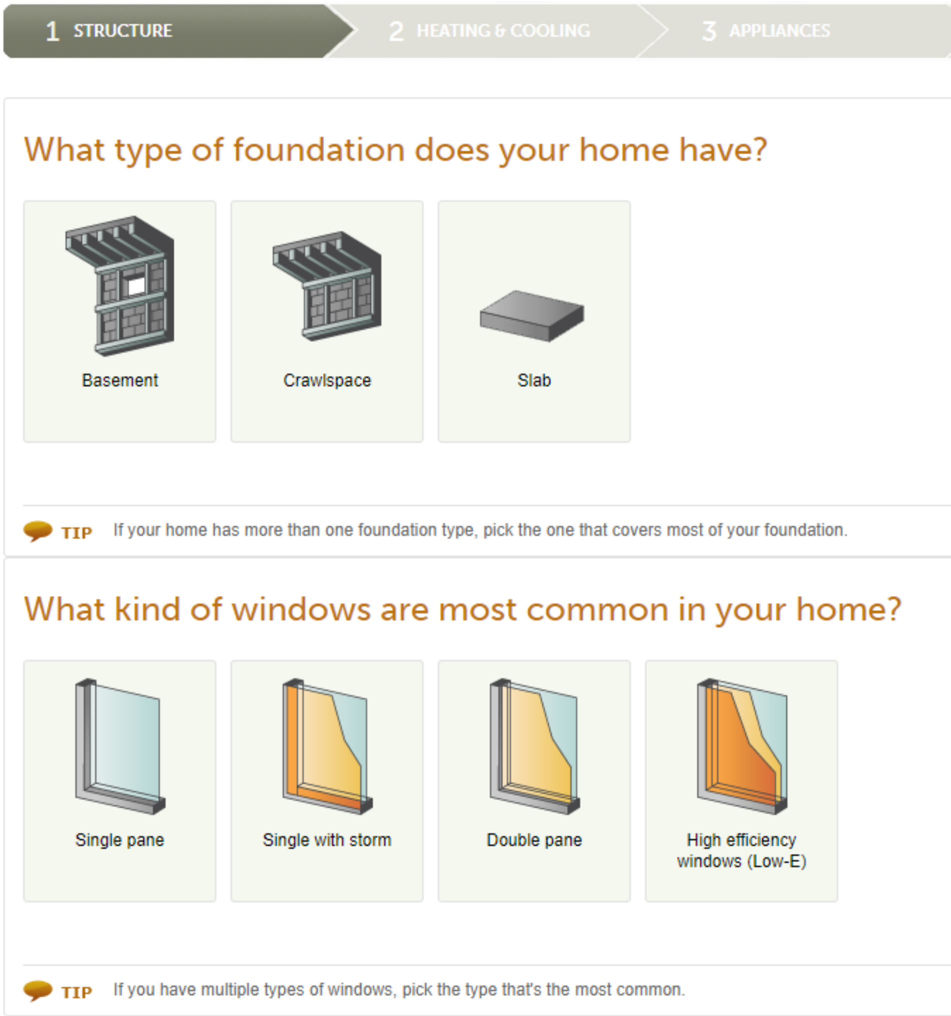


Figure 4.5: Energy survey from EnergySavvy [8]

Once the survey is completed, a set of energy retrofits is deployed along with a brief description of each item.

4.4.5 Energy+

Energy+ is an energy utility from Canada that provides electricity to approximately 65000 customers in the City of Cambridge, the Township of North Dumfries and within the County of Brant [20]. As in the former case of CPS Energy, the utility uses an online

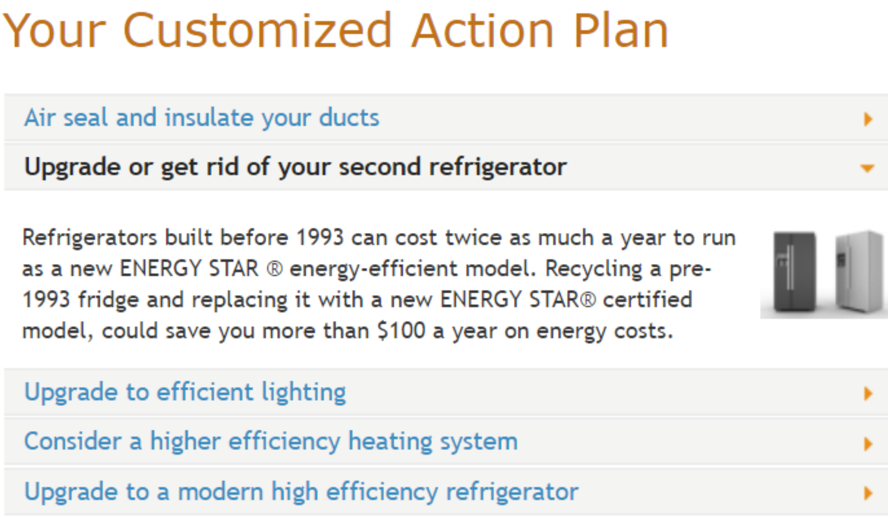


Figure 4.6: Energy retrofits from EnergySavvy [8]

auditor tool in order to promote customer engagement but in that particular case the utility developed the software itself.

The tool is an online survey that asks for specific questions about the appliances and usage of the facility equipment and calculates the potential energy savings based on the theoretical efficiency improvements achievable. Although the method is quite rudimentary, an estimation of the potential savings pops up at the end of the test along with a list of energy retrofits as Figures 4.7 and 4.8 show.

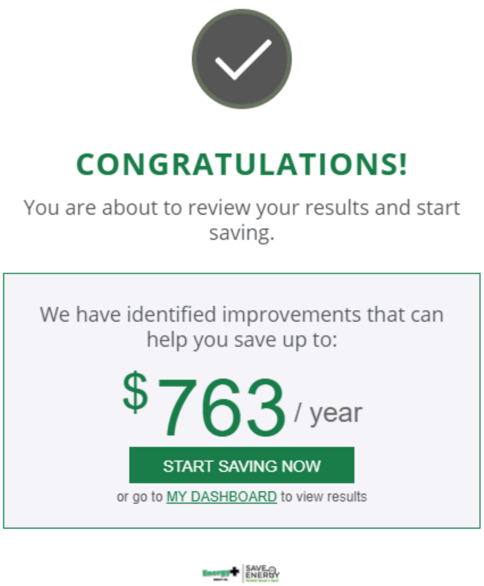


Figure 4.7: Estimated energy savings by the Energy+'s tool [9]

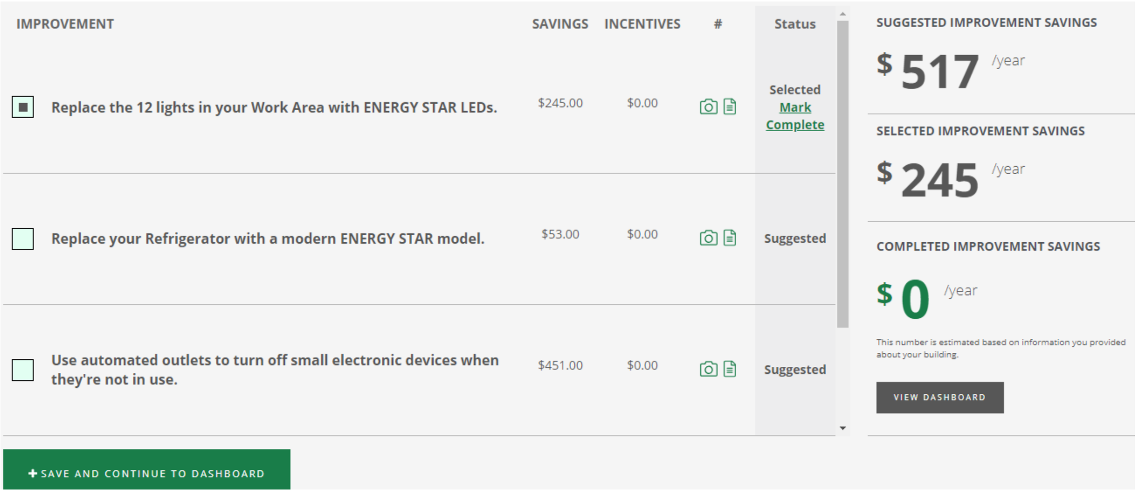


Figure 4.8: Energy retrofits from the Energy+'s tool [9]

4.4.6 DEXMA

DEXMA Sensors S.L is a Catalan company leader in energy management solutions. Their main product is the DEXCell Energy Manager which is an online platform for energy monitoring compatible with most of the monitoring technologies currently available in the market. On November 28th DEXMA launched a new product called EnergyGrader. It consists in an online platform for virtual energy auditing. The advantage of this platform is that the engine that carries out the energy analysis leverages DEXMA's database, which roughly contains 50000 locations all over the world. DEXMA's database has been built up thanks to DEXCell Energy Manager, the main product of DEXMA that has been gathering different consumption profiles and disaggregated data among the last 10 years. This data is anonymously used by the EnergyGrader's engine [21]. The information required to perform a virtual energy audit with the EnergyGrader is [10]:

- Energy invoices available.
- Year of construction of the building
- Total surface.
- Location by means of ZIP code in order to connect with a GIS meteorological database.
- Activity of the building.
- Facade type, choosing between mostly brick or mostly glass.

The platform has two format options, EnergyGrader for SME's and EnergyGrader for utilities. Both use the same engine to perform the audits but the first one has a more simple design and mainly focuses on displaying the energy recommendations whereas the second one shows a more detailed analysis and is still being developed. Figure 4.9 shows a screenshot of the platform EnergyGrader for SME's.

Figure 4.9: EnergyGrader SME's recommendations [10]

Chapter 5

Data analysis behind virtual energy audits

In this Chapter the insights of the theoretical analysis behind a deep virtual energy audit are exposed. The explanation is based on the engine developed by DEXMA Sensors S.L. [10] although some technical details are ruled out of the explanation due to intellectual property reasons. Figure 5.1 sketches the conceptual map behind the virtual energy audit. It can be seen that the above mentioned engine is composed by three elements, which are explained in this present Chapter. The inputs of this virtual auditor engine are also commented along with the library of recommendations, which its elaboration is one of the scopes of this project.

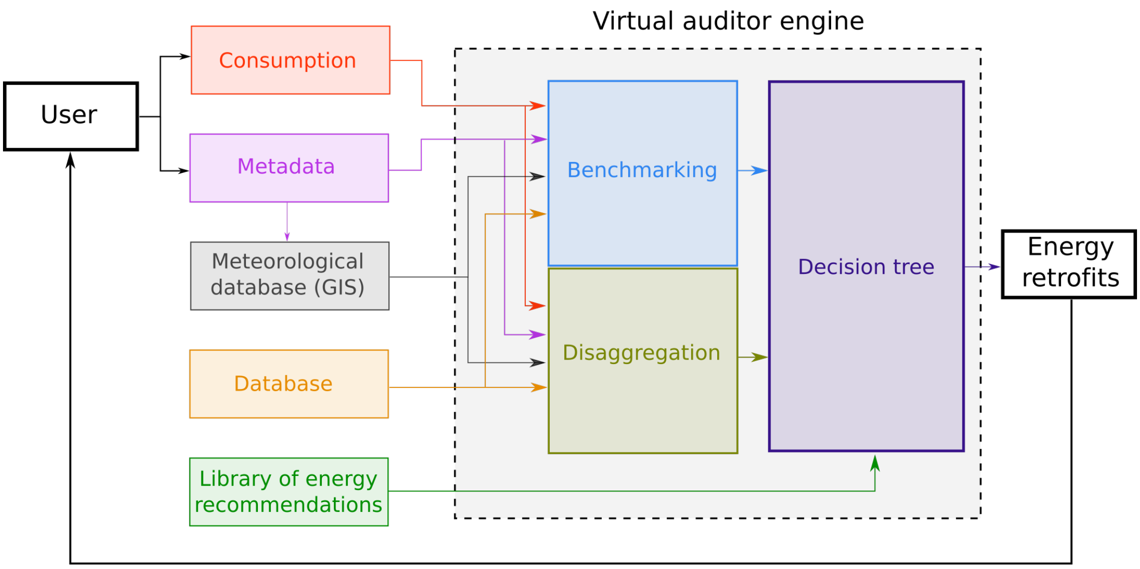


Figure 5.1: Conceptual map of the virtual energy audit

5.1 Inputs of the virtual auditor engine

5.1.1 Consumption data

As already mentioned in Chapter 4, the consumption data is a key point in the determination of the energy state. The frequency of these data is directly linked to the accuracy of the audit. If the frequency data is high enough, i.e readings under one hour periods, then activity hours can be deduced and in some occasions by means of NILM techniques the hours of usage of certain systems or appliances can be determined.

5.1.2 Metadata

The word *meta* comes from Greek and means ”beyond” or ”after” and used as prefix usually indicates a concept which is an abstraction behind another concept. In other words, metadata is data about some data. In some manner the metadata is employed to better understand and support other sources of data. For instance, when using a NILM technique it is crucial to know which appliances or systems the facility under analysis contains. When benchmarking two different sized buildings', the area might help to normalize and make the consumption better comparable. The metadata as explained in Chapter 4 usually consists in location, the activity, the inventory of the main loads or other technicalities of the main consumption systems and constructive details, i.e area, year of construction, insulation, etc.

5.1.3 Meteorological information

The local temperature is directly linked to the energy demand since it affects the consumption of the cooling and heating systems, which usually are the main loads in buildings. Meteorological data is used in the benchmarking and the disaggregation modules, it mainly consists in:

- Daily average humidity.
- Hourly average humidity.
- Daily minimum humidity.
- Daily maximum humidity.
- Daily average temperature.
- Hourly average temperature.
- Daily minimum temperature.
- Daily maximum temperature.
- Dew point.

Condition	Equation
$T_{max} < T_{base}$	$CDD = 0$
$\frac{(T_{max} + T_{min})}{2} < T_{base}$	$CDD = \frac{(T_{max} - T_{base})}{4}$
$T_{min} \leq T_{base}$	$CDD = \frac{(T_{max} - T_{base})}{2} - \frac{(T_{base} - T_{min})}{4}$
$T_{min} > T_{base}$	$CDD = \frac{(T_{max} + T_{min})}{2} - T_{base}$

Table 5.1: Calculation for the Cooling Degree Days

- Air pressure.
- Wind speed.
- Solar azimuth angle.
- Cloud coverage.
- Precipitation.

This data is extracted from the nearest meteorological database by means of the ZIP code or location of the facility. From the temperature information, the Cooling and Heating Degree Days (CDD and HDD respectively) are obtained. The CDD quantifies how many degrees is the temperature above the reference value T_{base} during one day. In that manner, during the warm periods of the year the variable CDD usually presents high values whereas during cold periods the value tends to be zero. If there are any particular anomalies, e.g a summer week that is colder than usual, those patterns are reflected in the CDD values, therefore the CDD is a good estimator for power cooling demand. In the same manner, the HDD quantifies how many degrees is the temperature below the reference value T_{base} during one day and it is related with the demand of heat. As in the CDD, abnormalities in temperature that may affect the use of the heating system are reflected in this variable. The mathematical definition of CDD and HDD is depicted in tables 5.1 and 5.2.

The use of this parameters will be seen further on on the theoretical explanation of the benchmarking and the disaggregation modules.

5.1.4 Database

The database refers to the stored information that the virtual energy auditor possesses and uses as reference values in order to assess the energy state of the building under analysis. This information usually consists in the load curves of a huge portfolio of buildings and their relative metadata. This will be used in the benchmarking module when the performance of the building will be compared with the ones in the database.

Condition	Equation
$T_{min} > T_{base}$	$HDD = 0$
$\frac{(T_{max} + T_{min})}{2} > T_{base}$	$HDD = \frac{(T_{base} - T_{min})}{4}$
$T_{max} \geq T_{base}$	$HDD = \frac{(T_{base} - T_{min})}{2} - \frac{(T_{max} - T_{base})}{4}$
$T_{max} < T_{base}$	$HDD = T_{base} - \frac{(T_{max} + T_{min})}{2}$

Table 5.2: Calculation for the Heating Degree Days

Moreover, if the stored buildings in the database have also data about their relative sub-consumption, i.e consumption of the lightening system, heating system, cooling system and others, then this sub-consumption data is employed in the disaggregation module with the aim to estimate the disaggregated consumption of the facility under analysis.

In general terms, it can be said that the more buildings in the database there are the better the accuracy of the audit will be. DEXMA's database consists in more than 50000 buildings worldwide with 10 years of historical consumption and sub-consumption data.

5.1.5 Library of energy recommendations

The library of energy recommendations gathers all the energy retrofits that the virtual energy auditor has in his or her portfolio. An energy retrofit contains information about the potential energy savings of the measure. This potential savings usually are in the form of range, where the minimum and maximum values are settled according to the experience on the field of multiple traditional energy audits. In the same manner, the CAPEX and OPEX are determined according to the existing technology. Usually this variables depend on other variables such for instance the CAPEX, which might normally depend on the area. An energy recommendation is an element with the following attributes:

- Name of the recommendation.
- Activity of the facility: It consists in a list of activities in where the recommendation is applicable. For instance, the replacement of the cooling units could be applied in offices, retail stores, restaurants, etc.
- Energy source. It refers to the portion of consumption where the recommendation affects, i.e surrogate the current bulbs for LEDs affects the consumption of lightening. This point is crucial in the determination of potential savings as it will be explained further on. For that, it is assumed that by means of the disaggregation module all the sub-consumptions are known. The energy source must be within one of the sub-consumptions determined by the disaggregation module, if not, the recommendation does not apply.

- Range of potential energy savings. As explained above, these values are obtained from the accumulated experience of several auditors. The final potential savings obtained from a particular measure is a value contained within the range and it is mainly determined by the decision tree as it will be explained further on.
- CAPEX (CAPital EXpeditures). It refers to the initial costs of the investment. It is difficult to predict the actual costs of an energy measure without an on-site visit, therefore, this value is usually an equation that depends on other variables.
- OPEX (OPeration EXpeditures). It refers to the maintenance costs of the energy measure along its whole lifetime. As in the former case, this value is usually an equation that depends on other variables.
- Lifetime. To know how many years the energy measure will last is crucial to calculate some economic metrics as will be explained further on in the decision tree.

The energy recommendations library of the EnergyGrader is not fully developed yet. Actually, a part of the scope of this work is to elaborate a preliminary version of this so-mentioned library. This is done in Chapter 6.

5.2 Virtual auditor engine

The virtual auditor engine collects all the previous data and selects a set of personalized energy retrofits for the facility under analysis along with some economic metrics that will help the facility manager to assess the feasibility of each recommendation. It is composed by the three following blocks.

5.2.1 Benchmarking module

The purpose of the benchmarking module is to compare the building under analysis with the correct group or cluster of buildings on the database in order to assess its potential of improvement. From a data science point of view, a cluster is a group of elements with similar characteristics. The key words here are ”compare” and ”the correct group of buildings”. In order to be able to make a good comparison, the reference buildings need to be as similar as possible with the building under analysis, if so, the differences in consumption will have more to do with efficiency reasons rather than for other external variables. The benchmarking module consists in two stages, the clustering according to the shape of the consumption curve and afterwards a more accurate selection within the buildings with similar load profile.

Clustering for annual patterns

The first stage is to cluster the buildings of the database according to the shape curve of one year of consumption, and then, associate the building under analysis into the correct cluster. The pattern of the consumption curve contains information about the building.

For instance, a building with an inefficient cooling system might consume a lot during the warm periods of the year as Figure 5.2 sketches, whereas a facility without cooling technology might have a drop in consumption during summer as Figure 5.3 represents since the heating system is not working. Is for that reason that it is important to compare curves that contain one full year of information so the variability between seasons is taken into account.

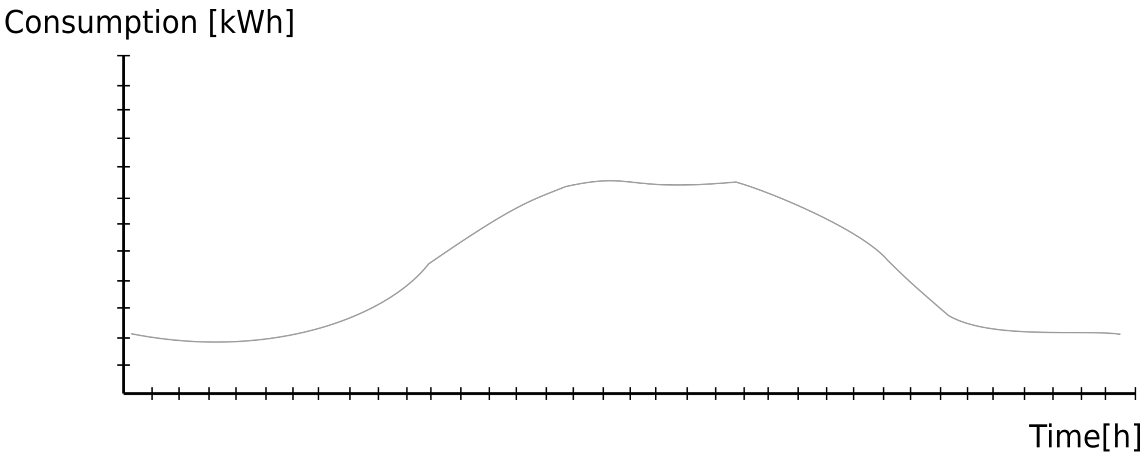


Figure 5.2: Load curve of a facility with high consumption of cooling

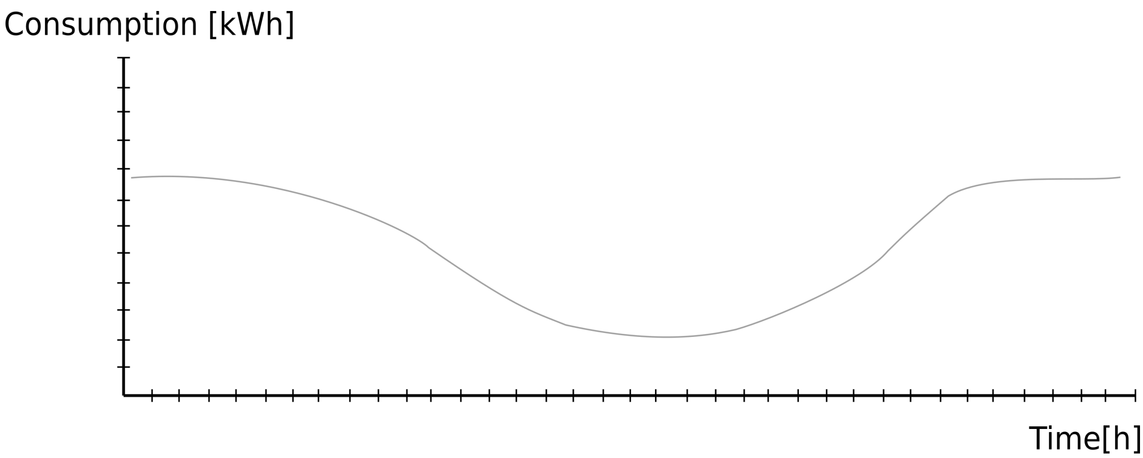


Figure 5.3: Load curve of a facility without cooling system

The procedure to group similar load curves is to use a clustering algorithm that minimizes the distance between each point of two load curves, in that manner, load curves with similar shape will have a lower accumulated distance and will belong to the same cluster as Figure 5.4 shows.

An algorithm that could work for that purpose is the k-means clustering. The description of this algorithm is as follows [22].

Given a set of observations $(x_1, x_2, ..., x_n)$ where each observation is a d-dimensional real vector formed by each one of the points of one consumption curve, then the k-means splits the n observations into $k(\leqslant n)$ sets or clusters $S = \{S_1, S_2, ..., S_k\}$ so as to minimize the

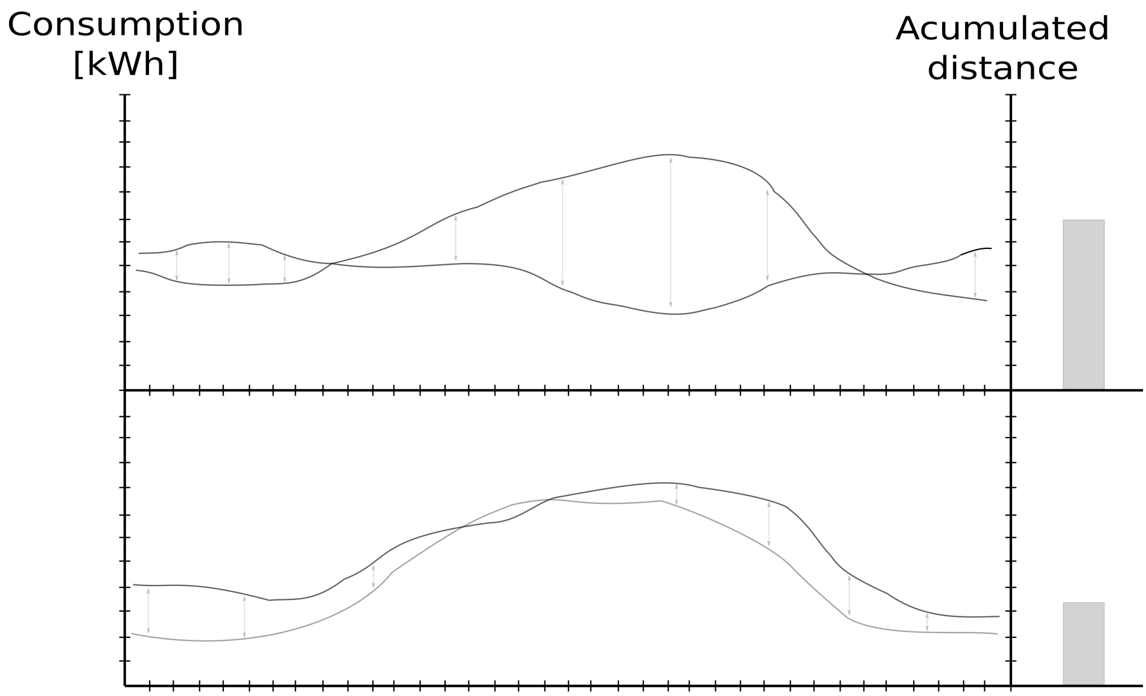


Figure 5.4: Pattern clustering with distance minimization

within-cluster sum of squares, i.e the variance.

$$S_i^{(t)} = \{x_p : \parallel x_p - m_i^{(t)} \parallel^2 \leqslant \parallel x_p - m_j^{(t)} \parallel^2 \forall j, 1 \leqslant j \leqslant k\} \tag{5.1}$$

According to equation 5.1, the element x_p (which is a vector containing all the points that conform a full year of consumption data) will belong to the cluster $S_i^{(t)}$ (at the iteration t) if the centroid of cluster $S_i^{(t)}$ (represented by $m_i^{(t)}$) has the lowest square distance of the rest of the existing centroids $m_j^{(t)}$ $\forall j, 1 \leqslant j \leqslant k$. A centroid is the arithmetic mean of a cluster. At the first iteration the centroids can be randomly selected but then they are calculated according to equation 5.2.

$$m_i^{(t+1)} = \frac{1}{\mid S_i^{(t)} \mid} \sum_{x_j \in S_i^{(t)}} x_j \tag{5.2}$$

The algorithm is iteratively re-calculated until the solution converge and there are no more points moving from one iteration to another. At that point the load profiles are aggregated according to similar patterns as Figure 5.4 sketches.

Before executing the algorithm it is extremely important to apply standard normalization to the data as equation 5.3 shows.

$$x_i' = \frac{x_i - \mu}{\sigma} \; \forall \; i = 1, ..., n \tag{5.3}$$

x_i is the point i of the vector conformed by the load curve "x". At this value the mean of the load curve μ is subtracted and the result is divided by the standard deviation σ of this so-mentioned serie. When this is done for each point of the load curve, then the result is the same load curve x' but with mean 0 and a standard deviation of 1. The purpose of this is to be able to compare only the shape of the curve regardless its order of magnitude. Figure 5.5 sketches the importance of that normalization. Curve a clearly looks more similar to curve c in terms of shape however, curve a is more similar to be b in terms of absolute consumption. This means that facilities a and b could be similar in size, but certainly what determines how the energy is consumed has more to do with the load profile rather than the size, implying that buildings a and c would actually have similar usages.

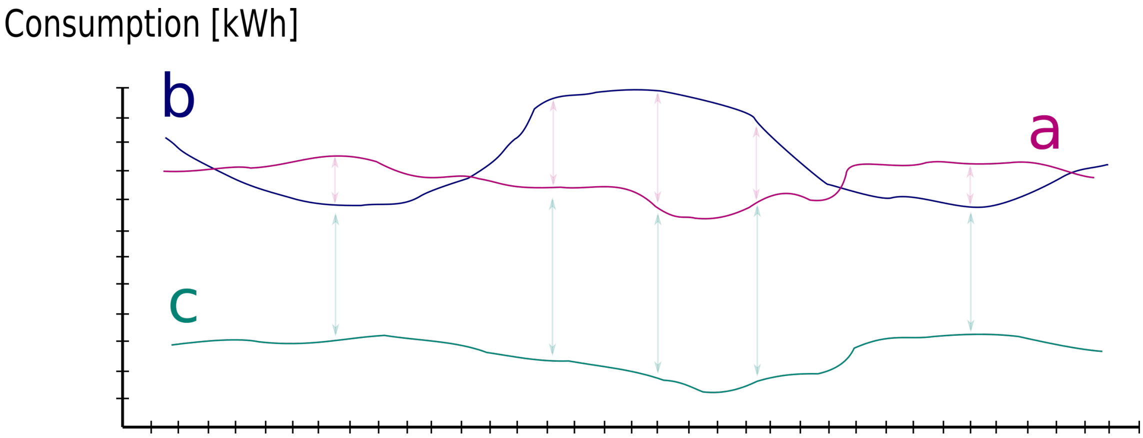


Figure 5.5: Clustering example without normalization

However, when applying the k-means algorithm the accumulated point-to-point distance of curves a and b is lower than from curves a and c, hence, the result of the algorithm would not be the expected one. What it is achieved when normalizing each dataserie is to eliminate the variability induced by the size, therefore, any differences in point-to-point distance will be due to the shape of the curves. Under this conditions, k-means will cluster the data correctly as Figure 5.6 shows.

Once this process has been executed and the data of the database is correctly clustered, by following the exact same algorithm the consumption curve of the building under analysis can be associated to a cluster. When this is done, it can be ensured that the buildings on that cluster consume energy similarly meaning that not only probably is their activity the same but there also will be their singularities i.e their period of inactivity will probably be the same, energy peaks occur similarly, etc.

Benchmarking with similar sites

Once the clustering of buildings with similar consumption curve is done, the next step is to find even more similarities with buildings within the same cluster. The scope of this is to narrow down the cluster and ensure that the buildings used as reference are similar and as comparable as possible to the one under analysis. In that manner, the conclusions

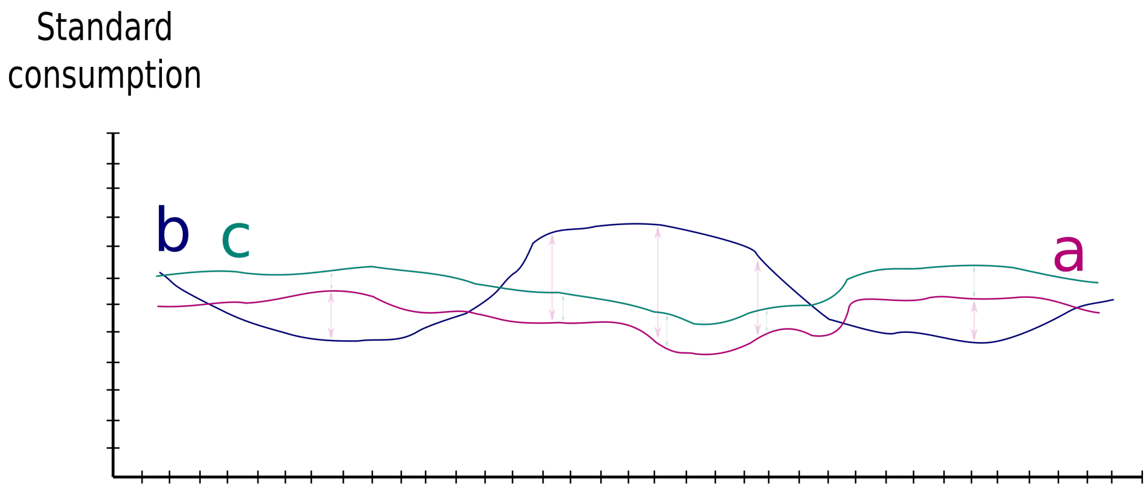


Figure 5.6: Clustering example with normalization

of the virtual audit gain robustness. The idea is that according to the experience of the online energy auditor some extra parameters are added in order to better analyze the data and discard the buildings which its benchmarking would not make sense and would compromise the veracity of the audit.

Starting with the cluster of buildings with similar annual load profiles, again, the k-means algorithm is applied but this time the square distance to minimize is the one with the curves defined by the energy auditor. The output of this will be another subset of clusters in where the buildings will be classified according to the similarity of their defined curves. As example, some of this curves could be:

- Monthly consumption curve normalized by unit area.
- Heating Degree Days of the last 12 months.
- Cooling Degree Days of the last 12 months.

An important parameter that the energy auditors take into account in order to benchmark facilities is the consumption of the building relative to its area. This can be reflected in the first curve. The monthly consumption normalized by area is calculated for all the buildings in the cluster of similar load profiles. Other curves that are also calculated are the monthly HDD and CDD curves for all the buildings on the so-mentioned cluster.

As mentioned above in this Chapter, the weather is directly linked to the energy consumption and the metrics used to assess this impact are the HDD and the CDD. This is the reason of including this two other curves in the second part of the analysis. If the external conditions of the benchmarked buildings are as similar as possible, the remaining variability will be due to efficiency reasons rather than for other causes and the audit gets more accurate.

In the first stage of the benchmarking modules the k-means algorithm was applied to only one variable, i.e the point-to-point distance between normalized consumption curves.

However, when multiple variables are under analysis, the importance of each variable is not always the same. This is taken into account by associating a predefined weight to each of the variables. This weigh is decided according to the experience of the virtual energy auditor and allows to module the impact of each variable in the benchmarking module.

A part from this three variables, additional dataseries can be built up to better analyze and benchmark the buildings according to the available information and the design criteria and experience of the virtual energy auditor.

Once this process is done, a set of clusters is obtained and the analyzed facility will belong to one of this clusters. Moreover, it is possible to compare the building under analysis with the ones belonging to its cluster. Since each building will have its own normalized consumption curve, its own HDD and CDD curves, the point-to-point accumulated distance for each curve can be calculated. In that manner, this metric will allow to assess how near or how far is the building under analysis with the less or the more consuming buildings of the cluster. The nearer the building is with the less consuming of the buildings, the less room of improvement it has in terms of potential energy savings. On the other way around, the more further the building under analysis is with the less consuming one, the higher the potential energy savings will be. This distances can be used to assess the potential energy savings.

To assume that this distances are related with the potential energy savings is the core idea of the virtual energy audit. The fact that the buildings are as similar as possible reduces the causes of consumption variability, being efficiency the main determiner of the position in the cluster.

5.2.2 Disaggregation module

Machine learning algorithms

Once the benchmark is performed and the potential energy savings are known, it is time to determine where the energy can be saved from. The aim of the disaggregation module is to numerically determine how the energy is consumed, which part of the total portion corresponds to the different subsystems that conform the facility. The different subconsumptions will mainly depend on the data available on the database of the energy audit and the metadata obtained from the building under analysis, e.g the case of facility that has not cooling system.

To deal with that, different machine learning techniques can be applied. Machine learning consists in the use of computational methods to ”learn” information directly from data without relying on a predetermined equation as a model. The algorithms adaptively improve their performance as the number of samples available for learning increases [23].

The machine learning techniques that could be applied in the disaggregation problem are the supervised learning algorithms, which are used to build a model to make predictions based on the accumulated experience of a data set [23][24]. For the case of the disaggregated module, the data set would be the database of the virtual energy auditor. This database will have a huge portfolio of buildings from where its sub-consumption is known. The idea is to apply a supervised learning algorithm using that data and build a model capable of predicting the sub-consumption of the building under analysis. Algorithms capable for that purpose are [24]

- Decision tree.
- Random forest.
- Support vector machine.
- Gradient boosting algoriths: GBM, XGBoost, LightGBM or CatBoost.

All the above mentioned techniques have in common that they consider a data-point as a variable to be predicted that has a set of attributes. The idea is that by analyzing those attributes the variable under analysis can be predicted. Going through the details of the above mentioned algorithms is out of the scope of this work, however, in order to get a glimpse of the main idea behind this techniques the Decision tree algorithm, which is the simpler one of the list, will be explained as example.

Example of application of Decision trees

The Decision tree is an iterative algorithm that consists in splitting the data in two groups. The splitting is done with the aim of making the groups as distinct as possible. The algorithm ends when no more splittings can be done. In order to split a group, a question about one of the attributes is formulated. Depending on the answer, a particular element will belong to one group or the other. Intuitively speaking, the idea behind the algorithm is to formulate the right questions in manner that at the end of the process the elements of the resulting groups are as homogeneous as possible. If so, the resulting decision tree will be able to correctly classify an upcoming element and therefore predict its value, since the values of each formed group are known.

Note that this is possible only if a proper number of elements had been analyzed to form the tree. This elements that in some manner "train" the tree are known as training set. Once the tree is formed then it needs to be validated. This is done by another set of data which is called the validation set. Usually, when elaborating a decision tree from an existing database, the normal procedure is to use 80 % of the database as training set and the remaining 20 % as validation set [25].

From a technical point of view, the procedure followed to split the data consists in maximizing the information gain. All the attributes are considered to split the data and the information gain is calculated for each of the possibilities. The one which has the maximum information gain will determine how the first splitting is done. The same process is carried out with each of the formed branches until the information gain is 0, and no more splittings are done.

Before being able to calculate the information gain, first of all, the entropy of each group needs to be calculated. In information theory, the entropy can be represented by equation 5.4 and in some manner represents the amount of information that contains a certain set of data [25].

Color	Size	Shape	Edible?
Yellow	Small	Round	Yes
Yellow	Small	Round	No
Green	Small	Irregular	Yes
Green	Large	Irregular	No
Yellow	Large	Round	Yes
Yellow	Small	Round	Yes
Yellow	Small	Round	Yes
Yellow	Small	Round	Yes
Green	Small	Round	No
Yellow	Large	Round	No
Yellow	Large	Round	Yes
Yellow	Large	Round	No
Yellow	Large	Round	No
Yellow	Large	Round	No
Yellow	Small	Irregular	Yes
Yellow	Large	Irregular	Yes

Table 5.3: Example of data

$$E(set) = \sum_{i=1}^{n} -p_i \ log_2(p_i) \tag{5.4}$$

p_i is the probability that the event i occurs, and it will mainly depend on the selected attribute.

The following example is the classical one from an academic point of view for explaining this algorithm, and it helps to understand the procedure [25]. Considering the following set of objects which data is shown in table 5.3, a decision tree is built in order to predict the variable of interest, in that case, whether the object is edible or not.

The entropy of the general set would be as follows since there are 9 edible objects and 7 non-edible ones.

$$E(set) = -\left[\left(\frac{9}{16}\right) log_2\left(\frac{9}{16}\right) + \left(\frac{7}{16}\right) log_2\left(\frac{7}{16}\right)\right] = 0.9836 \tag{5.5}$$

By selecting the attribute size, since it has two values, two branches could be formed. The same procedure is applied to calculate the entropy of each of the branches and the results are sketched in Figure 5.7.

Now the information gain needs to be calculated. To do that, the entropies of the two child branches need to be added and weighted by their number of elements.

$$E(set) = \frac{8}{16} \cdot 0.8113 + \frac{8}{16} \cdot 0.9544 = 0.8828 \tag{5.6}$$

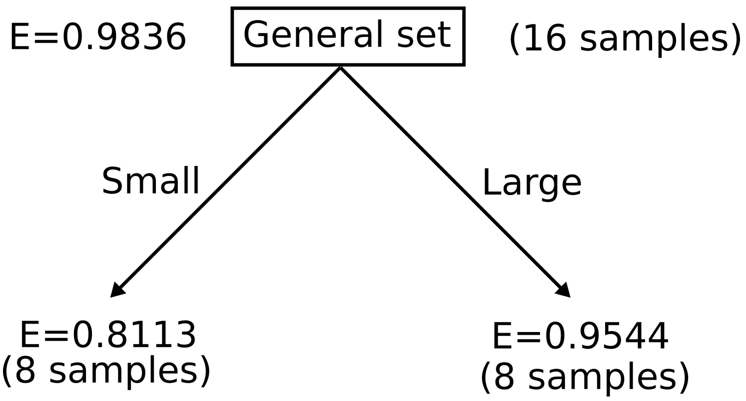


Figure 5.7: Example of decision tree construction

The information gain G is the entropy subtraction between the node and the total entropy of its child branches.

$$G(set) = 0.9836 - 0.8828 = 0.1008 \tag{5.7}$$

This procedure is done for all the combinations of the different existing variables. The one that has the maximum information gain will be selected to continue with the decision tree. The procedure is applied again for each of the following branches until there is no change in the information gain or no remaining variables to split.

Application in the disaggregation module

The above mentioned example is quite simple. The variables applied in the case of the virtual energy audit are more complex. For starters, a variable would be a location in the energy auditor's database. That location would have a lot of attributes, some from the metadata and others coming from the local weather conditions of the building. Examples of those variables could be:

- Activity of the building.
- Monthly consumption curve.
- HDD and CDD curves.
- Monthly humidity curve.
- Latitude.
- Total surface.
- Cloudy percentage.
- Consumption during winter.

- Consumption during summer.

The variable of interest in that case are the sub-consumption ranges. The possible sub-consumptions will mainly depend on the available data in the energy auditor's database. The scope of building a decision tree is that given the set of attributes of the building under analysis its sub-consumption can be correctly predicted. At the reality, other more complex techniques can be applied such the Random Forest or any of the Gradient Boosting algorithms, which concatenate different decision trees and other data mining techniques to perform more elaborated predictions [24]. The decision on which data mining algorithm should be used or which are the variables of interest to correctly disaggregate the data depend on the design criteria and the accumulated experience of the virtual energy auditor.

5.2.3 The decision tree

Once the benchmarking and the disaggregation modules are executed the potential energy savings and the estimated subconsumptions are known. With that, all the energy recommendations available in the library are executed by the decision tree module. Figure 5.8 sketches how the outputs of the disaggregation and benchmarking modules are used in that purpose.

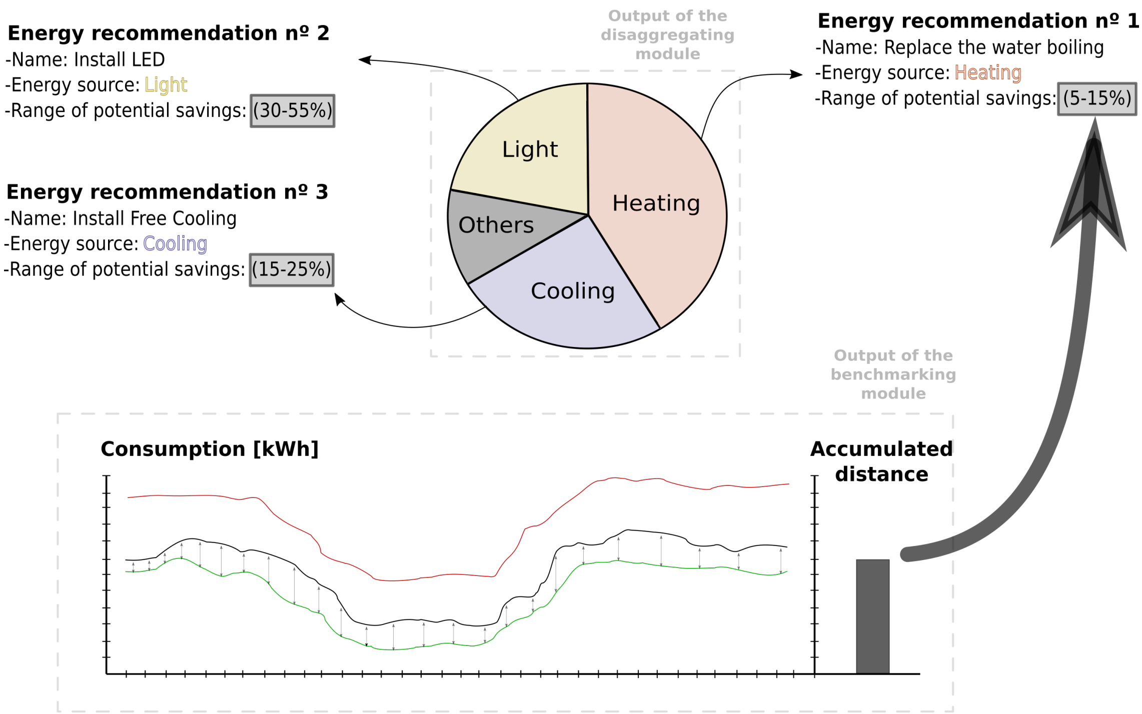


Figure 5.8: General scheme for the elaboration of energy retrofits

Each recommendation applies to its respective energy source. The total amount of each energy source is the output of the disaggregation module. It is mentioned before that each recommendation has a range of potential energy savings, however, is the decision tree the one who executes the recommendation and gives an exact value within the range for each recommendation. This exact value of potential savings is estimated according to the accumulated distance of the load profile of the building under analysis with the best building of the cluster. The closer the curve is to the less consuming building the closer will be the potential savings to the lower value of the given range.

Once this procedure has been executed for all the recommendations, then the decision tree calculates the economic metrics for each recommendation. This point depends on the design criteria of the energy auditor but some metrics that are usually employed are:

- CAPEX (CAPital EXpenditure). Is the initial investment required to apply the measure. It can be calculated since each recommendation usually has the CAPEX in the form of a function that depends on some metadata of the facility.
- OPEX (OPerating EXpenses). Is the maintenance or ongoing costs required to maintain the measure. It can be calculated since each recommendation usually has the OPEX in the form of a function that depends on some metadata of the facility.
- Payback. Since the energy price and the potential energy savings are known, it it possible to calculate the economic annual savings that will generate the energy measures. With that, it is possible to calculate how long it will take to recover the initial investment.
- Return on Investment (ROI). It is described according to equation 5.8.
- Net Present Value (NPV). It is a metric that consists in summing all the cash flows along the lifetime of the measure and taking into account the time value of money by means of the discount rate. It is described in equation 5.9.
- Internal Rate of Return (IRR). Intuitively speaking this metric evaluates how fast an investment would be received back. It is described in equation 5.10.
- CO_2 emissions. Since the potential energy savings are known, it is possible to calculate how many kg of CO_2 would have been emitted if the measure was not applied.

$$ROI = \frac{Gain\ from\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment} \tag{5.8}$$

$$NPV = \sum_{t=0}^{n} \frac{(Net\ Cash\ Flow)_t}{(1 + discount\ rate)^t} \tag{5.9}$$

$$\sum_{t=0}^{n} \frac{(Net\ Cash\ Flow)_t}{(1 + IRR)^t} = 0 \tag{5.10}$$

The most usual procedure is to sort the energy recommendations by payback. The ones that are not suitable for the building under analysis will have a considerably high payback and will not be shown to the final client. The threshold to show or not a recommendation to the final user is set according to the criteria of the virtual energy auditor. There are some cases in which the available metadata plays an important role in the recommendation assessment. For instance, for a building with no cooling technology the recommendations that refer to the improvement of the cooling system will not appear.

Chapter 6

Library of energy recommendations

In this Chapter the elaborated energy recommendation library is presented. Each recommendation is defined according to the existing literature and by studying some real cases found in traditional energy audits that had been analyzed. The following set of energy retrofits could be improved and extended according to the experience of the virtual energy auditor.

6.1 Install Free Cooling

Free cooling is an economic method for air-conditioning that takes advantage of the low outdoor temperatures to produce energy savings. When outdoor temperature is profitable the cooler external air is used to chill water in order to replace the need for operating chillers. This energy measure makes sense when the facility under analysis has an integrated ventilation system. With that, costs and potential energy savings can be [26]:

- Costs: 1000-5000 €
- Potential energy savings: 5-10 %
- Energy source: Cooling
- Lifetime: 15 years
- Areas of application: Offices, banking, retail or any kind of facility with a huge and centralized ventilation system.
- Metadata of interest: Whether the facility has or not cooling system instead of separated air conditioning units.

6.2 Solarisate the current heat pumps

SolarXenergy is a leader company in cooling technologies and they came out with the following energy measure to improve the efficiency of the heat pumps. Figure 6.1 sketches the conceptual idea behind their measure.

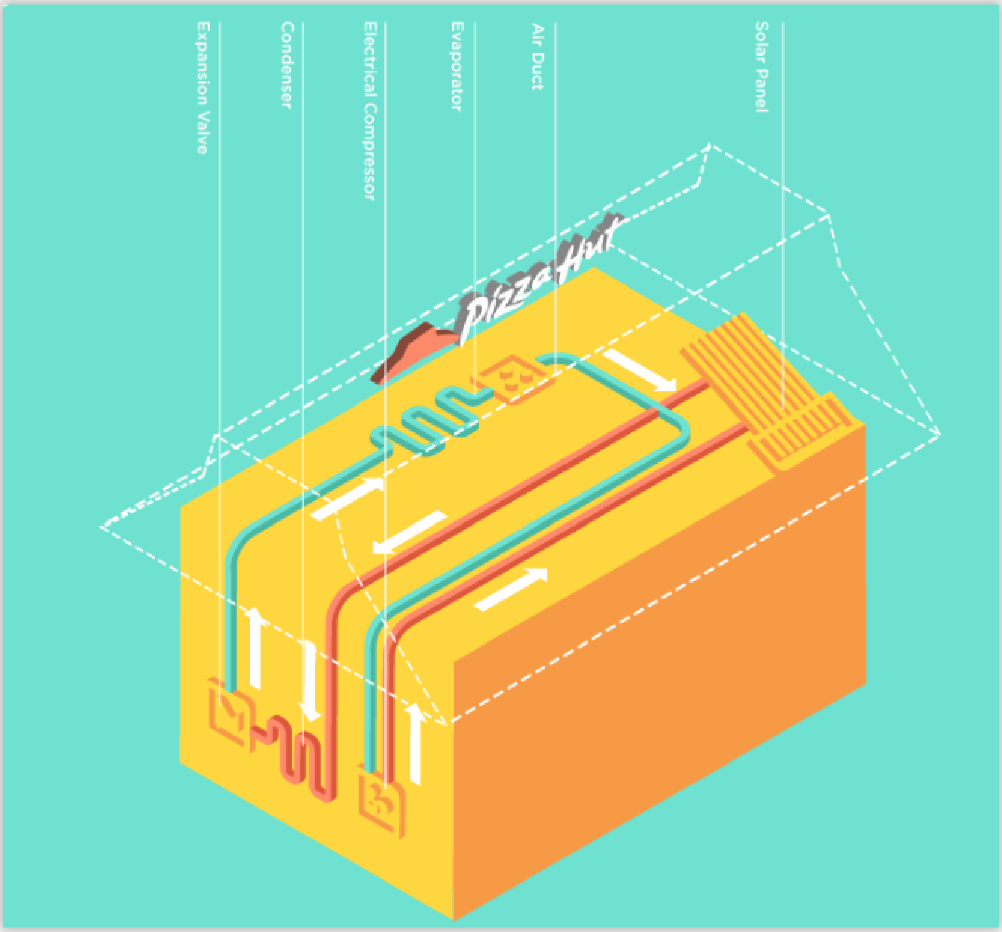


Figure 6.1: Conceptual scheme of the solarization technology [11]

It mainly consists in introducing an extra amount of heat at the exit of the compressor by means of a solar panel regulated by a by-pass valve. In that manner, the gas gets super-heated at the entrance of the condenser and it is able to transmit a greater amount of heat into the external air (Mpemba effect) enhancing the efficiency of the heat pumps.

This technique had successfully been applied to several facilities in South America and Spain [27]. SolarXenergy exposed its technology in its first congress at Barcelona on April the 19*th*. From that congress, the following characteristics concerning the technology had been gathered.

- Costs: 200 €/ kW of installed cooling/heating power
- Potential energy savings: 25-45 %

- Energy source: Cooling
- Lifetime: 15 years
- Areas of application: Shopping malls, offices or any kind of facility with and usage of cooling over 70 % of the time.
- Metadata of interest: Whether the facility has or not cooling system, usage of the cooling system.

6.3 Install presence sensor for the control of cooling

Presence control for cooling is a technology that pursues the efficient use of cooling systems allowing economical and energy savings by using the cooling only when needed. The idea is to use the cooling systems in relation to the human occupancy of the area in where the cooling system is supposed to work. The technical details of that potential measure are detailed as follows [28] [29].

- Costs: 15 €$/m^2$
- Potential energy savings: 10-80 %
- Energy source: Cooling
- Lifetime: 15 years
- Areas of application: Museums, hospitals
- Metadata of interest: Whether retrofit is already implemented or not. The activity of the facility or any relevant data about the lightening usage may contribute to determine the actual value of potential savings within the specified range.

6.4 Maintenance of the cooling system

The maintenance of the cooling system mainly consists in cleaning up the filters of the outdoor units and the internal ones. The removal of dust and other particles from the outdoor unit filters might increase the performance of the unit around a 10 % [30] . The costs of that are considerably low and will mainly depend on the amount of units to be cleaned.

- Costs: $20 + 20 \cdot [units]$ €
- Potential energy savings: 5-15 %
- Energy source: Cooling
- Lifetime: 1 year

- Areas of application: Offices, hotels, banking, retail, hospitals, museums, in general, any kind of facility with cooling system.
- Metadata of interest: Frequency of maintenance

6.5 Replace the current lightening for LEDs

LED technology (Light emitting diode) is a technology that uses some properties of semiconductor devices in order to produce light. The main advantage of this technology is the low levels of consumption compared to other lighting technologies implying huge energy savings. The costs and potential energy savings of applying this measure are specified as follows [31] [30].

- Costs: 8 €$/m^2$
- X: binary variable that is 0 when the facility has fluorescent lighting technology and 1 otherwise.
- Potential energy savings: (15-40)X + (50-80)X %
- Energy source: Lightening
- Lifetime: 20 years
- Areas of application: Offices, banking, retail, hotels, restaurants.
- Metadata of interest: Current technology of the lightening system

6.6 Install presence sensors for light controlling

Presence control for lighting enables a more efficient use of lightning systems. It can generate cost and energy savings by engaging lighting systems only when needed. The idea is to only use the lighting systems in relation to the human occupancy of the area where the lighting system is supposed to work. The costs and range of savings are determined according to the accumulated experience and some practical cases [28][32].

- Costs: 15 €$/m^2$
- Potential energy savings: 30-70 %
- Energy source: Lightening
- Lifetime: 15 years
- Areas of application: Offices, banking, retail, hotels, restaurants.
- Metadata of interest: Current technology of the lightening system, hours of actual use of the illuminated zones.

6.7 Install day-light dependent regulation for the lightening system

Daylight dependent regulation contributes to reduce the consumption of the lightning equipment by optimizing the lighting level together with external lighting sources. Specially in common or public areas of the building, when the system detects enough environmental lighting from external sources, switches off or reduces the light intensity. The presence of natural sources of light will mainly determine the actual range of potential energy savings [33]. Concerning its costs, the state of the art of this technology allows its easy implementation and integration [28].

- Costs: 15 €/m^2
- X: binary variable that is 1 when there is a considerable source of natural light. Otherwise the variable has 0 value.
- Potential energy savings: (25-45)X %
- Energy source: Lightening
- Lifetime: 20 years
- Areas of application: Offices, banking, retail, hotels, restaurants.
- Metadata of interest: Current technology of the lightening system, percentage of natural light coming from the outside.

6.8 Insulate the ducts of the heating system

In a facility with a centralized heating system powered by a water boiler, most of the times, adding an extra layer of insulation to the conducting water ducts (especially the ones circulating outside the areas to be heated) reduces significantly the heat losses. The insulation materials are not expensive and they are easy to be installed [34]. Concerning the potential energy savings, some studies had been performed in large consumers such as supermarkets and offices. The average savings were 10-20 m^3 of natural gas per year for each meter of insulated duct [30].

- Costs: 0.88 €/m of insulated duct
- Potential energy savings: 105.5-211 kWh/m of insulated duct
- Energy source: Heating [Natural Gas]
- Lifetime: 10 years
- Areas of application: Offices, supermarket, retail.
- Metadata of interest: Any detail referring to the heating technology used.

Model	Rated Power (kW)	Price (€)	Efficiency
Hermann Micraplus condens 30 (Saunier Duval)	26.5	959	98.20%
Ariston Clas Premium EVO 30 EU ErP	27.3	1099	97.60%
IsoFast Condens 35-B (H-ES)	32.8	1937	98.30%
Isomax F35 (Saunier Duval)	35	2298	98.00%
Junkers Cerapur Excellence-Compact ZWB30/32-1A	30	1598	94.00%
Condens F45 (Saunier Duval)	45	3597.33	98.00%
Vaillant Turbotec Plus VMW ES PT 32	32	2140.43	91.00%
Talia Green System HP	45	4910.18	97.00%

Table 6.1: Market analysis of the current water boilers options

6.9 Replace the current water boiler for a newer technology

New technology solutions allowed higher efficiency ratios for the water boilers currently available in the market compared with the older ones. In order to assess this potential energy recommendation, a market research of different technologies has been carried out and exposed in table 6.1. Those models had been compared with an older water boiler from 2004, the GN72 that had a thermal efficiency of 87 % [35]. For the study only boilers fueled with natural gas had been considered in order to make the recommendation more scalable since natural gas is the most used fuel in water boilers.

From table 6.1, average costs and efficiency gains (compared with a reference efficiency of 87%) had been extracted and are shown as follows.

- Costs: 63.8 €/kW of thermal power
- Potential energy savings: 4-11 %
- Energy source: Heating [Natural Gas]
- Lifetime: 15 years
- Areas of application: Offices, retail, hotels, hospitals, museums, restaurants, bars.

- Metadata of interest: To know the current heating technology and how old is the equipment.

6.10 Maintenance of the heating system

Maintenance tasks are essential for a proper performance of the heating system, especially when it consists on radiators. The accumulation of air inside the ducts and in some parts of the radiators causes conduction losses and extra work for the water pump. This air needs to be removed, since according to the accumulated experience of the manufacturers it can cause an overall reduction in efficiency of 10 %. The operation to remove the air from a radiator is known as bleeding the radiator. This is something simple to do that does not take more than 10 minutes per radiator. If the facility is considerably large, a professional could be hired to do the job (cost of the professional 20 €/hour). The recommendation can be summarized according to the following metrics.

- Costs: $20 + \frac{10}{3} \cdot [\mathrm{n}^o \ radiators]$ €
- Potential energy savings: 10 %
- Energy source: Heating [Natural Gas]
- Lifetime: 1 year
- Areas of application: Offices, retail, hotels, hospitals, museums, restaurants, bars.
- Metadata of interest: To know the current heating technology and if they had a radiators system. Frequency of maintenance.
- Lifetime:

6.11 Reduce base consumption by unplugging turned off equipment

Most of the electronic equipment consumes energy even though being turned off. This consumption is very low, but considering that the devices are usually plugged 100 % of the time at the end of the year the energy cost associated to that consumption could be signification. This consumption is known as standby consumption and depends on the device. Its specific value can be known by the manufacturer but usually, from the accumulated experience of some energy auditors this value usually varies between 1 and 10 % of the total consumption. The energy recommendation can be summarized as:

- Costs: 0 €
- Potential energy savings: 1-10 %
- Energy source: Others

- Areas of application: Offices, retail, hotels, museums.
- Metadata of interest: Any relevant data about how many kW are permanently connected.

6.12 Behavioral energy measures

It it obvious that the cleanest energy is the one not being consumed. According to the accumulated experience of some energy auditors a rational use of energy could mean a reduction of the total energy bill between 3.6-5.5 % [35] [30]. By rational use it is understood that people consumes energy only when it is required, turning off the lights when required, turn off monitors and computers when not being used, etc.

- Costs: 0 €
- Potential energy savings: 3.6-5.5 %
- Energy source: Others
- Areas of application: Offices, retail, hotels, hospitals, museums, universities.
- Metadata of interest: Number of people interacting with the facility.

6.13 Tinting the windows

Tinting a window consists in installing a thin film that retains undesired radiation such as infrared and ultraviolet rays. In that manner, the amount of heat passing through the windows gets reduced and the air conditioning units have less work load during summer. In the same manner, this effect contributes to keep the heat inside the facility during winter. Figure 6.2 shows an image of the installation of a tinted film cell in a window. It can be appreciated the difference in color perceived from the exterior.

The costs of this measure depend mainly in the film quality but they are compressed between 45 and 75 €/m_2 of window [36]. The potential energy savings are estimated to be around 30 % of the cooling consumption [37]. The measure can be summarized as follows:

- Costs: 45-75 €/ m^2 *of window*
- : X: area of windows with outdoor contact.
- Potential energy savings: Around 30 %
- Energy source: Cooling
- Areas of application: Offices, retail, hotels, museums, schools, universities.
- Metadata of interest: Usage of the cooling, total area of windows.

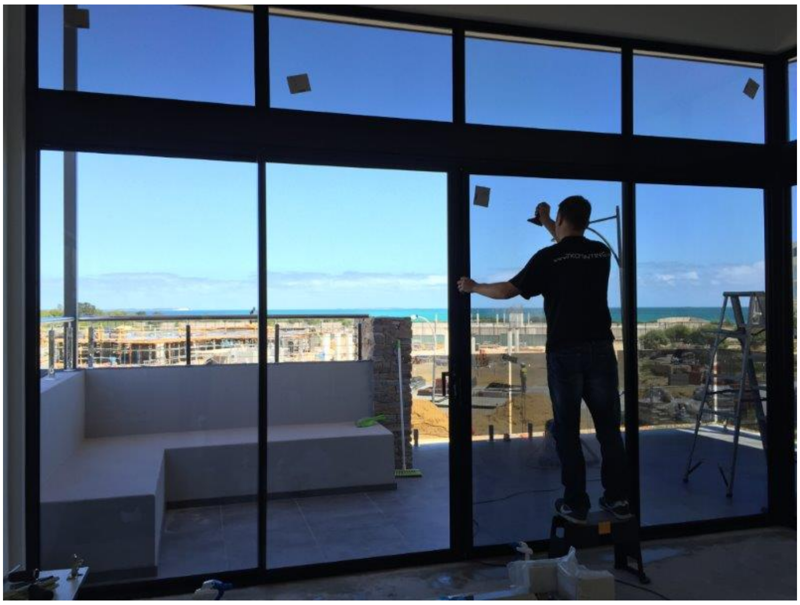


Figure 6.2: Results of tinting a window, before and after [source: Internet]

6.14 Install thermal solar panels

Another strategy to reduce your energy costs is to start producing your own energy. Thermal solar panels are a good solution to solve the needs for sanitary hot water [38]. Once the installation costs are depreciated the energy obtained is free. The costs for a thermal panel are compressed between 3500-6800 € [39]. Despite its variability in terms of efficiency (since the heat production is strongly linked to the weather conditions), it is assumed that a single solar panel could produce the equivalent energy that a person consumes in sanitary hot water [38]. The energy measure is summarized as follows.

- Costs: 3500-6800 €/person
- Potential energy savings: 100 % of the SHW (Sanitary Hot Water) of the building
- Energy source: Heating
- Areas of application: Offices, retail, hotels, museums, schools, universities.
- Metadata of interest: The amount of energy spent in SHW, the number of persons in the facility, the location.

Chapter 7

Real case application

In this Chapter some of the elaborated recommendations will be inserted in the library of recommendations of EnergyGrader for utilities and will be executed on a real case in order to assess its performance. Not all the recommendations could be applied since the software is not fully developed. There are still some specific inputs that can not be implemented yet.

7.1 Summary of the implemented recommendations

The following table 7.1 summarizes the library of recommendations elaborated in Chapter 6 and it details case by case whether a recommendation has been implemented or not and why. The current version of EnergyGrader only deals with electrical energy sources therefore the recommendations involving natural gas or other fuels are automatically discarded for the real case application. In other cases, some recommendations require certain inputs that the EnergyGrader can not provide by now. However, with the upcoming developments and improvements of EnergyGrader, the library of energy recommendations is expected to be fully implemented in the near future.

The code used to implement the above mentioned recommendations can be seen in annex B.

7.2 The facility under analysis and traditional energy audit results

The study is done based on a real energy audit performed on DEXMA's offices that can be seen in [35]. In that study the EnergyGrader tool was employed to assess DEXMA's potential energy savings, however, the energy recommendations library was not implemented. From the traditional energy audit the following recommendations list on table 7.2 was proposed.

Note that the red-marked recommendation refers to the heating system which is powered by natural gas, therefore, this recommendation will not be proposed by the EnergyGrader

Recommendation	Implemented in EnergyGrader	Comments
Free cooling	YES	-
Solarize	NO	There is not an input to insert the installed kW hours of the cooling system
Presence sensor for cooling	NO	Does not apply to offices
Maintenance cooling	NO	There is not an input to insert the number of units of cooling
Change to LEDs	YES	-
Presence sensor for lightening	NO	There is not an input for the usage of lightening
Day-light dependent regulation for lights	YES	-
Insulate ducts	NO	Only electric analysis
Replace water boiler	NO	Only electric analysis
Maintenance heating	NO	Only electric analysis
Reduce base consumption	YES	-
Behavioral measures	YES	-
Tinting windows	NO	There is not an input for the area of window
Install thermal solar panels	NO	There is not an input for the ocupation

Table 7.1: Summary of the insertion state of the energy recommendations into EnergyGrader

Recommendation	Initial investment [€]	Annual savings [€]	Payback [years]
Replace the water boiler	1937	307.59	6.3
Change to LED and dimming sensors	1852.40	265.61	7
Reduce standby consumption	0	163.8	-

Table 7.2: Recommendations from the traditional energy audit carried at DEXMA's offices [35]

Month	Monthly Consumption real data [kWh]	Monthly Consumption estimated value [kWh]	Estimated cooling consumption [kWh]	TOTAL
January	1,585	0	0	1585.00
February	1,619	0	0	1619.00
March	1,665	0	0	1665.00
April	1,560	0	6.8	1566.80
May	-	1397.21	231.2	1628.41
June	-	1450.84	591.6	2042.44
July	-	1539.88	935	2474.88
August	1,583	0	142.8	1725.41
September	1,713	0	0	1713.18
October	1,609	0	0	1609.00
November	1,504	0	0	1504.00
December	1,277	0	0	1277.00

Table 7.3: Electrical consumption data used as input in the EnergyGrader analysis [35]

since the gas consumption remains out of the scope of the analysis. The second measure (change to LED and install dimming sensors) helps to reduce the consumption in lightening and to dim the lights according to the external light conditions measured by the sensors. The last measure aims to cut off some base consumption mainly by unplugging some office equipment when it is not used [35].

7.2.1 Data input

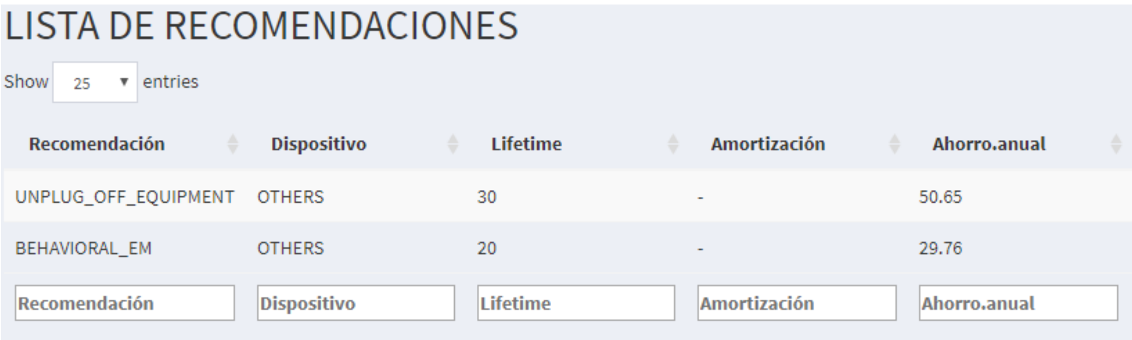
The data used as input is the same one used in [35] and it mainly is:

- One year of electric consumption data, which can be seen in table 7.3.
- Location: Carrer de Napols 189, 08013, Barcelona, Spain. This data will be used to internally track the local weather conditions.
- Area: 450 m^2
- Activity: Office building

7.3 EnergyGrader results

Once introduced the above mentioned data and once the library of energy recommendations had been inserted, the results of executing the EnergyGrader can be seen in Figures 7.1 7.2.

Figure 7.1: Screenshot of the output of EnergyGrader for utilities


LISTA DE RECOMENDACIONES

Show 25 entries

Recomendación	Dispositivo	Lifetime	Amortización	Ahorro.anual
UNPLUG_OFF_EQUIPMENT	OTHERS	30	-	50.65
BEHAVIORAL_EM	OTHERS	20	-	29.76
Recomendación	Dispositivo	Lifetime	Amortización	Ahorro.anual

Figure 7.2: Proposed energy recommendations by the EnergyGrader

In Figure 7.2 it can be seen that the two proposed energy recommendations are unplug the turned off equipment and apply behavioral energy measures. The two measures combined together aim to reduce the standby consumption and can in some manner be equivalent to the third recommendation proposed by the traditional audit (reduce standby consumption).

Recommendation	Initial investment [€]	Annual savings [€]	Payback [years]	Energy source
Free cooling	4000	117.58	34.02	Cooling
Day light dependent regulation	6750	112.09	60.22	Lightening
Change to LEDs	3600	129.03	27.73	Lightening
Unplug turned off equipment	0	40.39	0	Others
Behavioral measures	0	36.79	0	Others

Table 7.4: Results of executing all the implemented recommendations for DEXMA's offices

7.4 Assessment of the energy recommendations library

The first thing to remark is that the EnergyGrader did not propose all the recommendations present in its library, however, all them have been calculated. The results of executing all the implemented recommendations for DEXMA's offices are presented in table 7.4.

The EnergyGrader does not show recommendations above 10 years payback, this is why the first three recommendations on table 7.4 do not appear in the results screen despite being calculated. By comparing the recommendations on table 7.4 with the ones provided by the traditional energy audit presented in table 7.2 [35] it can be remarked that:

- As already mentioned, the replacement of the water boiler is not studied since this version of the EnergyGrader only studies the electric energy sources.
- Installing free cooling is not feasible as the traditional energy audit already proved [35].
- The two recommendations proposed by the EnergyGrader sum an annual potential savings of 80.41 € and both aim to reduce base consumption. From the traditional energy audit [35], the measure "Reduce standby consumption" was estimated to achieve 163.80 € of potential annual savings. Note that the EnergyGrader in some manner managed to come up with a similar recommendation and estimated the potential savings from a more conservative approach.
- The lightening recommendations calculated by the EnergyGrader are already proposed in the traditional energy audit, the difference resides in the investment. The lightening measure is estimated to cost 1852.40 € according to the traditional audit and the lightening measures of the EnergyGrader have a total cost of 10350 €. This difference is because in the traditional energy audit the lightening recommendation affects a specific area in the office whereas the EnergyGrader calculates the measure for the whole facility ($[8€/m^2 + 15€/m^2] \cdot 450m^2 = 10350$ €).
- Despite miscalculating the costs, the annual savings of the lightening measures calculated by the EnergyGrader are 241.12 €, which are quite similar to the 265.61 € estimated by the traditional energy audit.

- The time of execution of the virtual energy audit was 40 seconds and no kind of on-the-spot measurements were required.

Conclusions

In this work the concept of virtual energy audit is explained and a list of 14 energy recommendations is elaborated and studied in a real case application. Once having analyzed both traditional and virtual energy audits, one of the main conclusions is the huge advantage in terms of cost, time and scalability of the virtual energy audits compared with the traditional ones.

In Chapter 4 the current state of the art of the virtual energy audits was presented. In there, it was seen that a virtual energy audit could have different levels of accuracy depending on the data requested and the data available by the auditor in his or her database. From that, it can be concluded that this disruptive technology has the following areas of application:

- It can be a tool for utilities with the aim to prompt customer engagement. It has been seen in utilities like Energy+ or the case of EnergySavvy. Even though a reduction in consumption implies a decrease in their net income, the additional value that an online energy assessment tool adds to their customers is a cost effective measure for their business.

- They are an excellent tool for companies with a large number of buildings. With this innovation, virtual energy audits could be carried out annually with the aim to narrow down the on-the-spot analysis of more inefficient buildings and focus the resources where they are needed the more.

- Following with the above idea, the same massive analysis approach could be used for energy managers. There are many companies that their business core is to be the energy managers of other companies. With virtual energy engine tool, not only could an energy manager proactively work with his or her clients but it also could be an excellent tool to assess business opportunities in new clients.

To sum up, the insights of this technology had been studied and because of that, the elaboration of the energy recommendations library had been carried out more effectively. If the working principle of the virtual auditor engine is known, it can be understood that the core of the assessment resides on the engine, therefore, each energy auditor is free to tune their library of recommendations according to his or her accumulated experience and specific information of the client under analysis.

The energy recommendations library had been partially validated in Chapter 7 against a traditional energy audit. The results were satisfactory and prove the growing potential of the virtual energy audits.

Acknowledgements

Per començar, m'agradaria donar les gràcies a tot Dexma per oferir-me la possibilitat de fer aquest projecte i per donar-me l'oportunitat de formar-me dins d'aquest àmbit de l'enginyeria del qual he après molt. En especial, vull donar les gràcies a en Daniel Utges, el Miguel Cruz, a l'equip de Data Science de Dexma per ajudar-me en les parts més tècniques i a l'Oriol Gomis per dirigir-me el projecte.

A més a més, vull donar les gràcies a la meva família, pel seu suport al llarg de la meva etapa acadèmica que finalment conclou aquí i per la seva energia i recursos que sempre m'han dedicat incondicionalment.

A tots ells, gràcies

Annex A

Budget and environmental impact

A.1 Budget

The fact that this work does not include an experimental set-up makes the budget cheaper, because it will only include the necessary office supplies and the human resources. The estimated prices considered in the next sections do not include the taxes.

A.1.1 Office supplies

The office supplies consists only in the computer used to do this work since free software has been employed to carry out the project implying no additional costs.

Concept	Unitary price [€/u]	Units [u]	Price [€]
PC Samsung NP-R530	529,95	1	529,95
Total			**529,95**

Table A.1: Hardware

A.1.2 Human resources

In this part of the work the activities are divided in two blocks: training and research and drafting. The price of each part is detailed in the table A.2.

A.1.3 Total budget

By adding the cost of the two previous sections the total cost of the project is obtained.

Concept	Price per hour [€/h]	Hours [h]	Price [€]
Training and research	35	320	11.200
Drafting	20	70	1.400
Total			**12.600**

Table A.2: Human resources

Concept	Price [€]
Hardware	529,95
Human resources	12.600
Total	**13.129,95**

Table A.3: Total budget

A.2 Environmental impact

The environmental impact is analyzed from two points of view: the environmental impact from the elaboration of the work and the one from the virtual energy audits.

A.2.1 Environmental impact from the project execution

The only resources used to elaborate this work that might have an environmental impact are the hours of use of the computer and its associated electric consumption. The equivalent CO_2 emissions can be seen in table A.4.

A.2.2 Environmental impact from the virtual energy audits

The environmental impact of the virtual energy audits is positive by far. It reduces the amount of on-site visits of the energy auditor and therefore the overall CO_2 emissions get reduced. Moreover, the whole process drives the final users to be more efficient and environmentally friendly prompting the implementation of energy efficiency measures.

Electricity source	Hours of use	Rated power [W]	Energy consumption [kWh]	Emissions [kg CO_2]
Computer	390	90	35.1	12.99*

Table A.4: CO_2 emissions for the project realization
*considering a CO_2 emission factor of 0.37

Annex B

Code implemented for inserting the library of recommendations into EnergyGrader

```
RETROFITS = [
   Retrofit({
       # "activity": ["HORECA", "OFICINA", "RETAIL"],
        "name": "FREE_COOLING",
       "energy_source": "HVAC",
       "min_savings": 0.5,
       "max_savings": 0.10,
       "capex": 4000,
       "capex_surface": 0,
       "opex": lambda x: 0,
       "lifetime": 15,
       "comfort": False
   }),

   Retrofit({
       # "activity": ["HORECA", "OFICINA", "RETAIL"],
        "name": "REGULACION_EN_FUNCION_LUZ_NATURAL",
       "energy_source": "LIGHTING",
       "min_savings": 0.25,
       "max_savings": 0.45,
       "capex": 0,
       "capex_surface": 15,
       "opex": lambda x: 0,
       "lifetime": 20,
       "comfort": True
```

```
    }),
    Retrofit({
        # "activity": ["HORECA", "OFICINA", "RETAIL"],
         "name": "CAMBIO_LAMPARAS",
        "energy_source": "LIGHTING",
        "min_savings": 0.15,
        "max_savings": 0.40,
        "capex": 0,
        "capex_surface": 57,
        "opex": lambda x: 0,
        "lifetime": 20,
        "comfort": False
    }),


    Retrofit({
        # "activity": ["HORECA", "OFICINA", "RETAIL"],
         "name": "UNPLUG_OFF_EQUIPMENT",
        "energy_source": "OTHERS",
        "min_savings": 0.01,
        "max_savings": 0.1,
        "capex": 0,
        "capex_surface": ,
        "opex": lambda x: 0,
        "comfort": True
    }),
    Retrofit({
        # "activity": ["OFICINA"],
         "name": "BEHAVIORAL_EM",
        "energy_source": "OTHERS",
        "min_savings": 0.036,
        "max_savings": 0.055,
        "capex": 0,
        "capex_surface": 0,
        "opex": lambda x: 0,
        "comfort": True
    })
]
```

Bibliography

[1] International Energy Agency. Key world energy statistics. Technical report, 2017. 9, 16

[2] International Energy Agency. World: Indicators for 2015. http://www.iea.org/statistics/statisticssearch/report/?product=Indicators&country=WORLD, May 2018. 9, 15, 16

[3] International Energy Agency. Iea energy statistics: Energy production world. http://www.iea.org/stats/WebGraphs/WORLD3.pdf, May 2018. 9, 17

[4] International Energy Agency. World energy outlook. Technical report, 2017. 9, 16, 17, 18

[5] Henry Summers. Summary of results: Firstfuel scaled field placement PG&E's emerging technologies program. Technical report, 2013. 9, 28, 29

[6] Abhay Gupta K.Carrie Armel. Is disaggregation the holy grail of energy efficiency? the case of electricity. Technical report, 2012. 9, 30

[7] EnergyCheckUp Project. SME energy checkup calculator. https://eu.mkbenergycheckup.nl/en, May 2018. 9, 30, 31, 32

[8] EnergySavy. EnergySavy calculator. https://engage.energysavvy.com/, May 2018. 9, 33, 34

[9] Energy+ Inc. Energy+ inc energy audit calculator. https://auditmybusiness.myenergyxpert.com/, May 2018. 9, 34, 35

[10] DEXMA Sensors S.L. Energy Grader. https://www.dexma.com/energygrader/, 2018. 9, 35, 36, 37

[11] Juan Gil Guitíerrez. SolXenergy IBÉRICA. Brochure, 4 2018. 9, 54

[12] Iter. On the road to iter: Milestones. https://www.iter.org/proj/itermilestones, May 2018. 18

[13] EU. Directive 2012/27/eu of the european parliament and of the council of 25 october 2012 on energy efficiency, amending directives 2009/125/ec and 2010/30/eu and repealing directives 2004/8/ec and 2006/32/ec. *Official Journal of the European Union*. 19

[14] Institut Català d'Energia. *Guia metodològica per realitzar auditories energètiques*. Generalitat de Catalunya, Carrer de Pamplona, 113, 08018 Barcelona, 2012. 19, 21

[15] Certicalia. Precio medio de: Auditoría energética. https://www.certicalia.com/precio/auditoria-energetica, May 2018. 27

[16] Henry Summers, David Chan and Curtis Hilger. Firstfuel scaled field placement. Technical report, 2013. 27, 28

[17] D. Utges. Anàlisi i innovació en el procés de realització d'auditories energètiques. De l'auditoria tradicional a l'auditoria virtual. Universitat Politècnica de Catalunya, 2015. 27

[18] Bidgely. Technical brief: 100 % appliance itemization. Technical report, 2016. 30

[19] EnergySavvy. Case study: CPS Energy Savers. Technical report, 2017. 32

[20] Energy+ Inc. Service area map. https://www.energyplus.ca/en/ourcompany/serviceareamap.asp, May 2018. 33

[21] DEXMA Sensors S.L. Introducing the Energy Grader. https://www.dexma.com/new-energy-grader/, 2018. Blog article. 35

[22] Chris Piech. K means. http://stanford.edu/~cpiech/cs221/handouts/kmeans.html, 2013. 42

[23] Inc The MathWorks. Mathworks support center: Machine learning. https://se.mathworks.com/discovery/machine-learning.html, 2018. 46

[24] Ray Sunil. Essentials of Machine Learning Algorithms (with Python and R Codes). https://www.analyticsvidhya.com/blog/2017/09/common-machine-learning-algorithms/, 2017. 46, 47, 50

[25] F. Aiolli. Machine learning algorithms. University lecture, 2008. Università degli Studi di Padova. 47, 48

[26] R.M. Lazzarin and M. Noro. *Energetic and economic savings of free cooling in different European climates*. Int J Low-Carbon Tech, 2009. 53

[27] Juan Gil Guitíerrez. 1er Congreso solarización de equipos de refrigeración y aire acondicionado (HVACR) en Barcelona. Hotel Front Marítim, Barcelona, Spain, 4 2018. SolXenergy IBÉRICA. 54

[28] Asociación de empresas para la eficiencia energética. Consumos, medidas y potenciales ahorros en edificios. a3e, 2015. 55, 56, 57

[29] Guía sobre empresas de servicios energéticos (ese). *Garrigues Medio Ambiente, Consultora Técnica y de Gestión Integrada del Medio Ambiente, S. L.* Fundación de la energía de la comunidad de Madrid, 2010. 55

[30] Centro de investigación de recursos y consumos energéticos. Pyme Energy CheckUp: 20 medidas para que ahorres energía (y dinero) en tu negocio. Energy CheckUp project, 2015. 55, 56, 57, 60

[31] Lucera Energía Colectiva S.L. Ahorro con bombilla LED. https://lucera.es/blog/ahorro-con-led, 2018. 56

[32] Craig DiLouie. Occupancy Sensors Eliminate Energy Waste. Facilitiesnet, 2008. 56

[33] DASSA Technologies S. L., Ctra. N−150, km 14.5, IPCT 08227 Terrassa (Barcelona). *INMÓTICA 2.0: IGS Prime DASSA technologies*, 2018. 57

[34] Leroy Merlin España S.L.U. Catálogo Leroy Merlin: Fontanería y tratamiento de agua. http://www.leroymerlin.es/fp/13446741/coquilla-28-mm-1-m-coquilla-1-m?pathFamilaFicha=500610, 2016. 57

[35] J. Romani. Disruptive alternative for energy audits: Traditional against online energy audits. Universitat Politècnica de Catalunya, 2018. 58, 60, 63, 64, 65, 67

[36] ClimatePro. How Much Does Window Tinting Cost? https://climatepro.com/2013/06/11/how-much-does-window-tinting-cost/, 2013. 60

[37] SAE Group. Window Tinting for Energy Efficiency. https://saegroup.com.au/window-tinting-for-energy-efficiency/, 2018. 60

[38] The Renewable Energy Hub. How much does a solar thermal system cost? https://www.renewableenergyhub.co.uk/solar-thermal-information/how-much-does-solar-thermal-cost.html, 2018. 61

[39] TheECOexperts. Solar Thermal Panels and Solar Water Heating. https://www.theecoexperts.co.uk/solar-panels/thermal, 2018. 61